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COMPUTER PROGRAM FOR PREDICTION OF FUEL CONSUMPTION STATISTICAL DATA FOR AN UPPER STAGE THREE-AXES STABILIZED ON-OFF CONTROL SYSTEM

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SUMMARY

This report describes a FORTRAN coded computer program and method to predict the reaction control fuel consumption statistics for a three axis stabilized rocket vehicle upper stage. It uses a Monte Carlo approach which is made more efficient by using closed form estimates of impulse useage. It includes effects of rocket motor thrust misalignment, static unbalance, aerodynamic disturbances, and deviations in trajectory, mass properties and control system characteristics. This routine has been used for over a decade to accurately predict the control fuel consumption statistics for the Scout launch vehicle second and third stage reaction control systems.

By selection of input data and options this routine can be applied to many types of on-off reaction controlled vehicles.

The psuedo random number generation and statistical analyses subroutines including the output histograms can easily be used for other Monte Carlo analyses problems.

A typical run of 200 samples requires 2 seconds of central processor time on a CDC CYBER 175 computer.

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LIST OF ILLUSTRATIONS

LIST OF SYMBOLS

a	limit cycle rate (deg/sec)
$C_{N_\alpha}S$	aerodynamic normal force coefficient slope with angle of attack times reference area (ft^2/radian)
C_DS	aerodynamic drag coefficient times reference area (ft^2)
DC	duty cycle
d	deadband halfwidth (degrees)
e	control error signal (degrees)
F	control force (lb_f)
g	gravitational acceleration (ft/sec^2)
H	control switching hysteresis ratio ($1 - d_{off}/d_{on}$)
h	altitude (feet)
I	moment of inertia (slug-ft^2)
I_{cap}	impulse required for capture maneuver (lb_f-sec)
I_{sp}	control fuel specific impulse (lb_f-sec/lb_m)
K_R/K_D	control system rate to displacement gain ratio (seconds)
K	a constant
l_c	control moment arm (feet)
N	number
P	probability level
PW	control motor firing pulse width (seconds)
Q	dynamic pressure (lbs_f/ft^2)
R_c	roll control moment arm (inches)
R_o	earth radius (feet)
RND	random normal deviate
RTI	booster induced roll angular impulse (ft-lb_f-sec)
SU	static unbalance (ft-lbs_f)
s	sample population standard deviation

LIST OF SYMBOLS (Cont.)

T	booster thrust (lb_f)
T_1	total system turn-on time delay (seconds)
T_2	total system turn-off time delay (seconds)
t	time (seconds)
V	velocity (ft/sec)
W	weight of vehicle (unsubscripted) (lbs)
W_i	control fuel weight (subscripted) (lbs)
x	body station measured positive toward tail (inches)
z	normal location on body from centerline (inches)

Greek Letters

α	angle of attack (degrees)
β	angle of sideslip (degrees)
γ	flight path angle measured from local horizontal (degrees)
Δ	incremental change
ϵ	misalignment angle of thrust (degrees)
ζ	azimuth (degrees)
θ	pitch attitude (degrees)
λ	forward cant angle of control motors (degrees)
π	ratio of circular circumference to diameter
ρ	atmospheric density ($slugs/ft^3$)
ρ_{xy}	correlation coefficient of x versus y variable
σ	standard deviation
ϕ	roll attitude (degrees)
ψ	yaw attitude (degrees)

LIST OF SYMBOLS (Cont.)

Subscripts

boost	during boost phase
C	control
CAP	associated with capture transient
coast	associated with coast period
cg	center of gravity
cp	aerodynamic center of normal force
D	disturbance
db	due to deadband
e	error
jet	control motor thrust
p	pitch
pr	predicted
R	roll
RETRO	retro following coast period
τ	booster thrust
W	wind
x	roll axis
y	yaw or transverse
o	initial value
1	start or on
2	end or off

Special Notation

•	dots above a parameter denote differentiation with respect to time.

1.0 INTRODUCTION

Reaction control system fuel consumption predictions for missiles, launch vehicles and space vehicles is usually required to be accurate so that weight can be minimized without unduly sacrificing mission success probability. Almost all reaction controlled missiles, launch vehicles and spacecraft would result in loss of control and mission failure if the control fuel useage were seriously underpredicted. On many vehicles overprediction of fuel requirements results in costly weight and volume penalties. The control system designer requires an accurate prediction of the statistical distribution of required impulse or control fuel to size the system. For missions with different coast periods a prediction of fuel useage is needed for propellant loading.

The method and computer program for predicting reaction control system fuel consumption statistics presented in this report has been used over the past fifteen years for the Scout launch vehicle second and third stage reaction control systems. Predictions using this method correlate well with flight data statistics. There is a slight tendency of the method to be conservative particularly at the low end of the probability distribution. This is due to an assumption of symmetric attitude limit cycle motion when undisturbed. In actuality a certain small percentage of vehicles achieve a near zero duty cycle in an axis rather than a symmetric limit cycle. As a result fuel consumption can be lower than the minimum predicted by the method.

Prediction of control fuel by this method is only as good as the accuracy of the input data; i. e., "Garbage in - garbage out." Scout experience in accurate prediction results from accurate knowledge of disturbance statistics, particularly rocket booster motor thrust misalignment. These are derived from detailed post-flight data analyses.

2.0 METHODOLOGY

The Monte Carlo method, used herein, is a relatively straightforward approach for predicting the statistical outcome of a highly non-linear process involving many variables. On-off reaction control system fuel consumption prediction for an upper stage rocket booster vehicle is a good candidate for this method. Large amounts of computer time are normally associated with the Monte Carlo approach. The method described herein is made efficient by using a series of closed form approximations to the fuel consumption during transient maneuvers and steady state operation. As a result several hundred samples can be computed with a few seconds of computer time on a high speed digital computer. Assumptions and equations used in the computer program are described in the following paragraphs.

2.1 Fuel Consumption Assumptions

Many assumptions are made to simplify the control fuel consumption prediction process. These include:

- Uncoupled axes (pitch, yaw, roll) each having its own set of control motors.
- On-off control has a simple deadband with constant switching slope for each phase of the flight (boost and coast) (see phase plane Figure 1).
- When undisturbed each axis control achieves a symmetric limit cycle motion.
- Disturbing torques and impulses are balanced by the control system without exceeding the zero rate deadband attitude error.
- Disturbing torques of sufficient magnitude to cause deadband crossing results in fuel consumption based on angular impulse balance plus symmetric limit cycle motion (Figure 1).
- When sets of reaction control motors are shared by two or more axes, each axis has full use of the motors in an uncoupled sense (e.g., yaw-roll mixing with four (4) jets is decomposed into a yaw-axis control with 2 motors in each sense and roll axes control with 2 motors forming a couple in each sense or direction).
- Sensor, computational, filter, and control motor switching hardware responses are treated as a simple equivalent time transport lag.
- Structural mode coupling with the control system is limited. An effective time transport lag is assumed to adequately account for structurally coupling. This is the case for the Scout launch vehicle (see Appendix D of Reference 1).
- Reaction control motor pulse shapes can be expressed as an equivalent square wave with appropriate thrust level and time delays.
- Aerodynamic stability derivatives are linear and can be expressed as a constant normal force coefficient slope with angle of attack and a constant aerodynamic center location.

- The vehicle is axisymetric in terms of moments of inertia and aerodynamic configuration.
- Trajectory parameters are as input and are not significantly perturbed by the off-nominal control behavior.
- Changing control fuel consumption does not alter the vehicle mass properties.
- Aerodynamic angle of attack includes the attitude error equal to the deadband halfwidth.

2.2 Equations

Equations describing the disturbances and fuel consumption are presented below. Trajectory geometry and definition of angles are presented in Figure 2.

2.2.1 Attitude Control Acceleration

Control angular accelerations are:

(2-1) $$\theta_c \ , \psi_c = \frac{F_c \ell_c}{12 I_y}$$

(2-2) $$\phi_c = \frac{2 F_c R_c}{12 I_x}$$

where,

$$\ell_c = [(X_C - X_{cg}) \cos\lambda + Z_C \sin\lambda]/12$$

2.2.2 Disturbances

Disturbing accelerations are due to booster thrust misalignment, vehicle static unbalance and aerodynamic torques.

$$\text{(2-3)} \quad \dot{\theta}_D = \frac{1}{I_y}\left[\frac{T\epsilon_{\tau p}(X_\tau - X_{cg})}{57.3\ (12)} + \frac{T\,SU_p}{W} - \frac{C_{N\alpha}SQ\alpha(X_{cg} - X_{cp})}{12}\right]$$

$$\text{(2-4)} \quad \dot{\psi}_D = \frac{1}{I_y}\left[\frac{T\epsilon_{\tau y}(X_\tau - X_{cg})}{57.3\ (12)} + \frac{T\,SU_y}{W} - \frac{C_{N\alpha}SQ\beta(X_{cg} - X_{cp})}{12}\right]$$

$$\text{(2-5)} \quad \phi_D = \frac{1}{I_x}\left\{\frac{T}{57.3W}\left(\epsilon_{\tau y}SU_p - \epsilon_{\tau p}SU_y\right) + \frac{C_{N\alpha}SQ}{W}\left(\alpha\frac{SU_y}{W} + \beta SU_p\right)\right.$$

$$+ SU_y\left[\frac{T}{\ell_c W}\left(\epsilon_{\tau p}\frac{(X_\tau - X_{cg})}{12} + \frac{SU_p}{W}\right) + \frac{C_{N\alpha}SQ\alpha(X_{cg} - X_{cp})}{\ell_c W}\right]$$

$$\left. - SU_p\left[\frac{T}{\ell_c W}\left(\epsilon_{\tau y}\frac{(X_\tau - X_{cg})}{12} + \frac{SU_y}{W}\right) - \frac{C_{N\alpha}SQ\beta(X_{cg} - X_{cp})}{\ell_c W}\right]\right\}$$

Angles of attack and sideslip are:

$$\text{(2-6)} \quad \alpha = \theta_{PR} - \gamma_{PR} - \gamma_{e1} + \alpha_W + \Delta\alpha_{db}$$

(see Figure 2)

$$\text{(2-7)} \quad \beta = \beta_{PR} + \zeta_{e1}\cos\gamma_{PR} + \beta_W + \Delta\beta_{db}$$

where γ_{e_1} is the perturbation flight path angle from previous stages plus the integrated change in flight path angle due to pointing error (deadband).

ζ_{e_1} is the equivalent flight path deviation in the yaw plane.

$$\text{(2-8)} \quad \gamma_{e1} = \frac{57.3}{V}\left[\frac{\gamma_{eo}V_o}{57.3} + \int \frac{T\,\theta_e}{W/g}\,dt\right]$$

$$\text{(2-9)} \quad \zeta_{e1} = \frac{57.3}{V}\left[\frac{\zeta_{eo}V_o}{57.3} + \int \frac{T\,\psi_e}{W/g}\,dt\right]$$

Angles of attack and sideslip due to wind are:

$$\text{(2-10)} \quad \alpha_W = 57.3\,\frac{V_w \sin\gamma_{PR}\cos(\zeta_w - \zeta_{PR})}{V + V_w\cos\gamma_{PR}\cos(\zeta_w - \zeta_{PR})}$$

$$\text{(2-11)} \quad \beta_W = 57.3\,\frac{V_w \sin(\zeta_w - \zeta_{PR})}{V + V_w\cos\gamma_{PR}\cos(\zeta_w - \zeta_{PR})}$$

Incremental angles of attack and sideslip due to pointing errors are:

(2-12) $$\Delta\alpha_{db} = \pm d - (\gamma_e - \gamma_{e1})/2$$

(2-13) $$\Delta\beta_{db} = \pm d + (\zeta_e - \zeta_{e1})/2$$

2.2.3 Control System Duty Cycles

Control system duty cycles during boost include those due to disturbance torque balance and undisturbed limit cycle behavior.

(2-14) $$DC_P = \frac{|\dot{\theta}_D|}{\theta_C} \quad ; |\dot{\theta}_D| \geqslant \dot{\theta}_{TEST}$$

(2-15) $$DC_P = \frac{|\theta_D|}{\dot{\theta}_C} + DC_{P\,(LIMIT\ CYCLE)} \cdot |\dot{\theta}_D| < \dot{\theta}_{TEST}$$

Test accelerations are those disturbing accelerations which define the boundary between a one-sided motor firing and crossing the deadband as shown in Figure 1 and 3.

2.2.4 Limit Cycle Motion

Undisturbed limit cycle motion results in a duty cycle dependent on control system characteristics.

(2-16) $$DC_{P(LIMIT\ CYCLE)} = \frac{K_1}{1 + \frac{K_1 \theta_C}{a}\left(\frac{d}{a} + T_1 - K_R/K_D\right)}$$

where,

(2-17) $$a = \frac{K_1 \ddot{\theta}_C T_2 (K_R/K_D - T_2/2) + dH}{2 K_R/K_D - T_1 - T_2}$$

$K_1 = 1$ for square wave pulse of control motor

(2-18) $$K_1 = 1 + \frac{t_p}{PW\,2\pi}(\pi - \nu - 2\mathrm{SIN}\,\nu)$$

for thrust with overshoot (Figure 4)

(2-19) $$PW = \frac{2a}{K_1 \dot{\theta}_C}$$

(2-20) $$\nu = \mathrm{TAN}^{-1}\left[\frac{\pi}{\ln\left(\frac{1}{F_p/F_c - 1}\right)}\right]$$

With control motor thrust overshoot the above equations for duty cycle are computed with one iteration starting with $K_1 = 1$.

When control acceleration is very high, long delay times can result in a deadband overshoot condition; i. e., the error signal crosses the total deadband before the opposite motor actually turns off. The control acceleration at which this occurs is:

$$(2\text{-}21)\quad \ddot{\theta}_{C_{MAX}} = \frac{d[2\, K_R/K_D - T_1 - T_2 - H\,(K_R/K_D - T_2/2)]}{T_2\,(K_R/K_D - T_2/2)\,(K_R/K_D - T_1/2)}$$

If $\ddot{\theta}_C > \ddot{\theta}_{C_{MAX}}$, the duty cycle becomes,

$$(2\text{-}22)\quad DC_P = \cfrac{1}{1 + \cfrac{T_1 - T_2 - A}{2T_2 - A + \cfrac{1}{K_R/K_D}\left[\frac{A}{2} + (T_2 - A)\right][T_1 - T_2 + A]}}$$

where,

$$(2\text{-}23)\quad A = \frac{2d\,(1 - H/2)}{\theta_C\, K_R/K_D}$$

Equations for yaw and roll duty cycles are the same.

2.2.5 Fuel Consumption

Control fuel consumption is dependent on the total impulse and effective specific impulse of the control motors. The specific impulse of the control motors used for pitch and yaw is assumed to be the same. A separate roll motor specific impulse can be used. In most cases the specific impulse during coast is different than during boost. Boost fuel consumption is:

$$(2\text{-}24)\quad W_{BOOST} = W_{BOOST_P} + W_{BOOST_Y} + W_{BOOST_R}$$

For pitch and yaw the fuel consumed is:

$$(2\text{-}25)\quad W_{BOOST_P} = \frac{1}{I_{SP}}\left[\int F_{C_P}\, DC_P\, dt + I_{CAP_P}\right]$$

where I_{cap} is the additional impulse needed to "capture" at separation/ignition from the initial conditions on rate and displacement,

$$(2\text{-}26)\quad I_{CAP_P} \cong \frac{F_C}{|\ddot{\theta}_C|}\left[\left|\dot{\theta}_0 + \frac{2\,(\theta_0 - d)}{K_R/K_D}\right| + 2\left|\dot{\theta}_C\right| T_2\right]$$

Roll fuel consumption includes an amount for booster roll torque (RTI) and pitch and yaw motor misalignment.

$$(2\text{-}27)\qquad W_{BOOST_R} = \frac{1}{I_{SP_R}}\left[\int F_{C_R}\, DC_R\, dt + I_{CAP_R} + RTI + \left|\epsilon_{JET_p}\right| \frac{Z_C}{R_C} \int F_{C_p}\, DC_p dt + \left|\epsilon_{JET_y}\right| \frac{Z_C}{R_C} \int F_{C_y}\, DC_y\, dt\right]$$

During the coast phase a symmetric limit cycle is assumed. Coast fuel consumption also includes (1) an incremental amount for transients due to deadband reduction from boost to coast system, (2) guidance program attitude rate changes in pitch and yaw, and (3) an optional retro maneuver with the boost pitch and yaw control motors.

$$(2\text{-}28)\qquad W_{COAST} = \frac{\int F_{C_p}\, DC_p\, dt}{I_{SP_p}} + \frac{\int F_{C_y}\, DC_y\, dt}{I_{SP_y}} + \frac{\int F_{C_R}\, DC_R\, dt}{I_{SP_R}} + W_{RETRO} + \Delta W_i$$

$$(2\text{-}29)\qquad W_{RETRO} = 2\left|F_{C_p} + F_{C_y} + F_{C_R}\right| \frac{t_{RETRO}}{I_{SP_{RETRO}}}$$

This assumes that the four boost pitch and yaw motors fire continuously and the system operates at a 100 percent duty cycle. Additional fuel for deadband reduction and torquing rate changes for each axis is

$$(2\text{-}30)\qquad \Delta W_i \cong \frac{F_C}{I_{SP}}\left[2\,T_2 + \frac{\left|\Delta\dot{\theta}_C + 57.3\, a_b + \dfrac{2\,(d_b - d_C)}{K_R/K_D}\right|}{57.3\, \ddot{\theta}_C}\right]$$

where $\Delta\dot{\theta}$ is the change in guidance pitch or yaw program rate (deg/sec)

a_b is the boost system limit cycle rate (rad/sec)

d_b, d_c is the boost and coast system deadband halfwidth (degrees)

K_R/K_D is the coast system rate to displacement gain ration (sec)

$\ddot{\theta}_C$ is the coast system control acceleration (rad/sec^2)

2.2.6 Trajectory and Vehicle Characteristics

Time histories of pertinent trajectory and vehicle characteristics are input to use in the calculations. These include dynamic pressure, velocity, booster thrust and propellant weight remaining, altitude, flight path angle, and azimuth. Wind velocity versus altitude is also input. Thrust misalignment is assumed to be described as an initial value and a slope which is correlated (see section 2.3).

Mass properties (center of mass station and transverse moment of inertia is assumed to be a second order polynomial of fraction of booster propellant consumed.

Given a three point curve (x_1, y_1), (x_2, y_2) and (x_3, y_3) the second order function is,

(2-31) $$y = y_1 + K_1 X + K_2 X^2$$

where,

(2-32) $$K_2 = \frac{y_3 - y_1 - \frac{X_3}{X_2}(y_2 - y_1)}{(X_3^2 - X_2 X_3)}$$

and,

(2-33) $$K_1 = \frac{(y_2 - Y_1)}{X_2} - K_2 X_2$$

The independent variable (x) is the fraction of booster propellant consumed, and the dependent variable is either center of mass station or the moment of inertia. The three input points should include the 0, 0.5 and 1.0 fractional propellant consumed values for best results. The burnout, or 1.0 fractional propellant consumed, values are used for coast calculations.

2.2.7 Optional Trajectory Characteristics

An optional input for certain trajectory calculations is available to approximate dynamic pressure, altitude and flight path angle. This option is used primarily where many parametric runs are required for which there are no trajectories. Given the initial flight path angle (γ_o), velocity (V_o) and dynamic pressure (Q_o) the density at ignition is calculated.

(2-34) $$\rho_o = \frac{2Q_o}{V_o^2}$$

This density is used with a standard atmosphere logarithmic density versus altitude data set to obtain initial altitude. Thrust, weight, and drag coefficient (C_DS) are input and used to propagate a gravity turn trajectory.

The set of first order equations used to propagate the trajectory is:

$$\dot{V} = \frac{g_0(T - C_D S Q)}{W} - g \sin \gamma \tag{2-35}$$

$$\dot{h} = -57.3 \frac{g \cos \gamma}{V} \tag{2-36}$$

$$\dot{\gamma} = V \sin \gamma \tag{2-37}$$

where,

$$Q = \tfrac{1}{2} \rho V^2 \tag{2-38}$$

$$g = \frac{g_0}{1 + \left(\frac{h}{R_0}\right)^3} \tag{2-39}$$

and,

$$g_0 = 32.174 \text{ ft/sec}^2$$

$$R_0 = 20{,}919{,}668 \text{ ft}$$

A Runge-Kutta integration subroutine is used to integrate these equations during boost to obtain the nominal trajectory parameters (V, h, γ, Q).

2.3 Statistical Analysis

The analysis method used in this routine is the Monte Carlo Technique. It is based on random sampling of a set of random input variables for the vehicle, trajectory, disturbances, and control system and computing the resulting total fuel consumption, boost fuel, coast fuel, and retro time. By computing a large number of such flights the statistical variation of fuel consumption is obtained. The method of treatment of input variables and analysis of output is listed below.

2.3.1 Input Random Variables

There are many random variables required as input. These variables are assumed to be Gaussian (Normal Distribution Function). A mean and standard deviation is entered for each of these variables. In all cases except booster thrust misalignment each variable is uncorrelated with all other variables.

For uncorrelated variables the random sample is:

$$X = \bar{X} + RND\,\sigma_x \tag{2-40}$$

where $\bar{x}$ is the mean value of x
σ_x is the standard deviation of x
RND is a random normal deviate (computed by routine)

Where there is a correlation between two variables as in the case of thrust misalignment the random samples are,

$$X = \bar{X} + RND_1\sigma_x$$

$$y = \bar{y} + RND_1\sigma_y\,\rho_{xy} + RND_2\sigma_y\sqrt{\frac{N-1}{N-2}\,(1-\rho_{xy}{}^2)} \tag{2-41}$$

where ρ_{xy} is the correlation coefficient of the x and y variables
N is the number of samples used to derive the correlation coefficient

The following is a list of random variables for input:

ϵ_{r_0}	initial value of booster thrust misalignment
$\dot{\epsilon}_r$	slope of booster thrust misalignment with time
$\dot{\theta}_0, \dot{\psi}_0, \dot{\phi}_0$	initial pitch, yaw and roll rate
θ_e, ψ_e, ϕ_e	initial attitude error in pitch, yaw, and roll
γ_e, ζ_e	initial flight path and azimuth error
Q_{FRACT}	dynamic pressure fractional deviation (Q/Q_{pr})
I_y	transverse moment of inertia
X_{cg}	center of mass station
SU_p, SU_y	pitch and yaw static unbalance
RTI	booster roll torque impulse
ϵ_{JET}	boost control motor misalignment angles
V_w	wind velocity versus altitude
ζ_w	wind direction
F_c	control motor force levels
I_{sp}	control motor specific impulse, boost and coast
F_p/F_c	pitch and yaw control motor overshoot ratio
t_p	pitch and yaw control motor time from on to peak thrust
t_{1m}	control motor effective turn on time delay
t_{2m}	control motor effective turn-off time delay
t_f	autopilot filter effective time delay
t_{RG}	autopilot rate gyro effective time delay
K_R/K_D	autopilot rate to displacement gain ratio
d	control system deadband halfwidth
H	switching hysteresis fraction

Other input variables are not treated as random.

2.3.2 Output Statistical Analysis

The routine calculates boost, coast, and total fuel consumption for N samples (flights). The output includes the values of fuel consumption with the calculated discrete probability levels for the N samples. In addition to these discretes, the sample population mean, standard deviation, skewness, and kurtosis are output for the parameters and the logarithm of the parameters. The probability distribution function parameters and key probability levels are based on three distribution functions; (1) Normal, (2) Log-Normal, and (3) Weibull. An equivalent level of significance for each of these three distributions functions is estimated and output based on the CHI-Squared Goodness of Fit Test.

When the fuel consumption samples are arranged in ascending order, the probability that the fuel consumption will be under a particular value is given by the following equation:

$$(2\text{-}42) \qquad P\,(\text{fuel consumption} < W_i) = \frac{N_i}{N+1}$$

where, W_i is a particular value of fuel consumption.

N_i is the sample number corresponding to W_i in the arranged fuel consumption distribution.

N is the total number of samples calculated.

It is desirable to obtain confidence intervals about a given probability level. This is also a function of the sample size. The two sided confidence interval for the standard deviation (σ) of a population of sample size N extracted from a Normal Distribution Function is provided by the following equation:

$$(2\text{-}43) \qquad \frac{\sigma}{s_x} = \frac{1}{\sqrt{1 \pm k_\gamma \sqrt{\frac{2}{N-1}}}}$$

where,

S_x is the sample standard deviation calculated from N samples.

σ is the true standard deviation.

k_γ is the number of standard deviations on a Normal Distribution which provide a probability level equal to the confidence coefficient (i.e., 0.95 confidence - 1.96σ, $k_\gamma = 1.96$). If only one side of the confidence interval (high side) is desired, the values of k_γ become based on cumulative Normal Distribution probabilities.

The confidence limits for other probability levels can be established assuming normality. That is, once the standard deviation is established with an upper confidence limit (say 95 percent) then the value at another probability level can be expressed as a number of standard deviations from the mean.

$$(2\text{-}44) \qquad y' = \bar{y} + \frac{Ks_x}{\sqrt{1 + k_\gamma \sqrt{\frac{2}{N-1}}}}$$

(95% confidence k_γ = 1.645 for one sided upper limit of confidence interval.)

where y' is the value of parameter 'y' at a probability level equivalent to the mean plus 'K' standard deviations on a Normal Distribution with the desired confidence coefficient.

$\bar{y}$ is the sample mean (assumed to be the true mean value of the distribution function).

K is the number of standard deviations required to provide the desired probability level.

The following is a short table for values of 'K' and 'k' for various probability levels and confidence coefficients.

Probability Level	K, k_γ (one-sided)
0.500	0
0.900	1.282
0.950	1.645
0.995	2.575
0.999	3.090

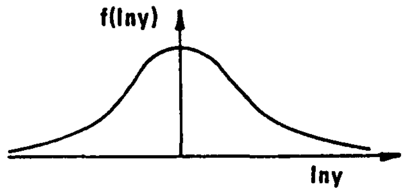
For example, to find the value of 'y' at 99.5% probability at 95 percent confidence, given sample mean, $\bar{y}$, and variance, S_x^2 , from N samples

$$(2\text{-}45) \qquad y' = \bar{y} + \frac{2.575\, s_x}{\sqrt{1 - 1\ 645 \sqrt{\frac{2}{N-1}}}}$$

In the case of fuel consumption, the distribution function is not usually Gaussian (Normal Distribution). Therefore, several approximate distribution functions are tested in the routine based on the Chi-Squared Goodness of Fit Test. These include the Normal, Log-Normal and three parameter Weibull distribution. The Log-Normal Distribution is simply a transformation of the 'y' parameter to the logarithm of 'y'. As shown in the sketch below, if the probability density function is one sided, the density function of the log 'y'

may approximate a Normal Distribution. If this occurs the properties of the Normal Distribution function such as probability level and confidence coefficient, can be applied to log 'y'.

Log-Normal Density Function



The three parameter Weibull distribution is also used. This distribution function is described in detail in Reference (2). The cumulative probability distribution function and density function can be described in terms of three parameters 'a', 'b', and 'c' by the following equations.

(2-46) $f(y) = \frac{c}{b} A e^{-A}$ density function

2-47) $F(y) = 1 - e^{-A}$ distribution function

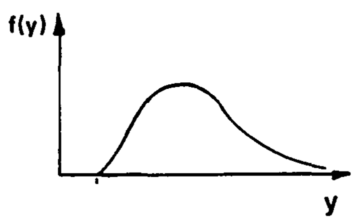
where,

$$A = \left(\frac{y-a}{b}\right)^c$$

and where 'a', 'b', 'c' are values greater than zero.

The probability density function can take on many shapes by varying the values of 'a', 'b', and 'c' and thus has application to a wide variety of problems. For this application it will have a shape similar to that shown in the sketch.

Weibull Density Function



For this distribution function the value of 'y' at a given probability level is given by:

$$(2\text{-}48) \qquad y = a - b\,[\ln(1 - P)]^{1/c}$$

where P is the probability level.

The routine prints out the parameters 'a', 'b', and 'c' determined from the fit based on McClintock's method of Reference (2). It also prints out the values of the parameter at several key probability levels. Calculation of confidence intervals for this distribution function is not included in this routine.

In addition to the statistical analyses described above, histograms of the output are made on the line printer for ready comparison.

3.0 PROGRAM DESCRIPTION

3.1 General

This routine is programmed in FORTRAN IV for the CDC CYBER 175 system. The only non-ANSI code used is the pseudo random number generator (RANF). An ANSI option for a replacement is identified in the program listing. The routine requires approximately 16 K words. Program flow, and user instructions are presented in the following paragraphs.

3.2 Program Flow

The program flows straight forward in five basic parts.

- Input option selection
- Input of all data
- Precalculation of boost phase time histories at integration steps
- Monte Carlo calculation of specified number of cases of fuel consumption or coast time
- Statistical analysis of results

Flow charts showing the general sequence are presented in Figure 5. A list of subroutines, their cross references and common blocks are presented in Figure 6. A description of the subroutines is given in the following paragraphs.

3.3 Subroutine Description

Most of the repeated specialized calculations are performed in the seventeen subroutines. Subroutine and common reference map is presented in Figure 6. The descriptions of each follow in alphabetical order.

ALTI

'ALTI' is used by subroutine TABGEN when the input option requires generation of certain trajectory parameters. Given the dynamic pressure and velocity it computes the altitude based on the logarithm of inverse density versus altitude table (RHO) supplied in labeled common "DRH" defined in the 'TABGEN' subroutine.

The call to the subroutine is:

CALL ALTI (ALTO, VO, QO)

ALTO	-	is the altitude in feet computed by this subroutine.
VO	-	is the velocity input (ft/sec).
QO	-	is the dynamic pressure input (lbs/ft^2).

ASCEND

This subroutine rearranges an array of numbers in monotonically increasing or descreasing order.

The call to this subroutine is:

CALL ASCEND (L, VAL, M)

L	-	is the number of values in array VAL (input).
VAL	-	is the array to be rearranged (input and output).
M	-	input option for ascending or descending order, M = 0 ascending M = 1 descending

CALCU

This subroutine is used with "RUNGE" to calculate the trajectory state variables and their first derivatives in TABGEN. It is based on equations 2-35 through 2-39.

The call to this subroutine is:

CALL CALCU

Input and output is passed through labeled common blocks 'DDI', 'DDY', and 'DRH'. 'DDY' contains the state variables and time information.

CHISQ

This subroutine is based on the Chi-Squared Goodness of Fit Test to a known distribution. It tests for level of significance against a Normal, Log Normal, and a Weibull distribution function.

The call to this subroutine is:

CALL CHISQ (N, A, CR, NG, AM, AS, WA, WB, WC, LD)

N	-	is the total sample size input.
A	-	is the input array of values.
CR	-	is the output computed level of significance.
NG	-	is the number of cells for the CHI-Squared Goodness of Fit Test.
AM	-	is the computed mean.
AS	-	is the computed standard deviation.
WA	-	is the Weibull 'a' parameter.
WB	-	is the Weibull 'b' parameter.
WC	-	is the Weibull 'c' parameter.

LD = 0 for a two parameter distribution (the Normal and Log-Normal).
LD = 1 for a three parameter distribution (Weibull).

Tables of the cumulative Normal probability distribution 'C' versus number of standard deviations 'Z' are embedded in this subroutine and are part of labeled common block 'CZ'.

CYCLE

'CYCLE' computes the duty cycle for the on-off control during symmetric undisturbed limit cycle operation. It is based on equations 2-16 through 2-20. It includes the option for deadband overshoot and overshoot type control motor thrust response.

The call to this subroutine is:

CALL CYCLE (THEC, GR, DR, H, T1, T2, DC, A, NDOVER, FCT)

THEC	-	is the control acceleration (rad/sec^2).
GR	-	is the rate to displacement gain ratio (K_R/K_D sec).
DR	-	is the deadband halfwidth (rad).
H	-	is the switching hysteresis fraction.
T1	-	is turn-on effective delay time (sec).
T2	-	is turn-off effective delay time (sec).
DC	-	is the computed duty cycle.
A	-	is the computed limit cycle rate (rad/sec).
NDOVER	-	is a deadband overshoot condition check = 0 no deadband overshoot = 1 deadband overshoot
FCT	-	is a factor computed by subroutine OVRF used when second order thrust response is indicated. If FCT is less than or equal to zero iteration on pulse width is not used.

HISTO

This subroutine sorts and plots a histogram on the line printer from an array of numbers. It must be given maximum and minimum values, the number of values and the increment for each cell of the histogram. The maximum cell count is 94 to fit the line printer. Below each cell the numerical value of the cell range and the count is printed. Asterisks are used to build the histogram.

The call to this subroutine is:

CALL HISTO (X, N, XMAX, XMIN, DX)

X	-	is an array of numbers for the histogram (input).
N	-	is the number of values in the 'X' array (input).
XMAX	-	is maximum value value in 'X' (input).
XMIN	-	is minimum value in 'X' (input).
DX	-	is the histogram cell width (input).

OVRF

This short subroutine computes a factor for control motor thrust when characterized by an overshoot response.

The call to this subroutine is:

CALL OVRF (T, OR, FAC)

T	-	is given time from zero thrust to first overshoot peak (sec).
OR	-	is given overshoot ratio (Fp/Fc).
FAC	-	is computed factor to be used for thrust level on short pulse widths.

PAGEHD

For output this subroutine ejects a page and prints run number and page number at the top of each page.

The call to this subroutine is:

CALL PAGEHD (NRUN, NPAGE, NLINE)

NRUN	-	is the input run number to be printed.
NPAGE	-	is the input page number to be printed.
NLINE	-	is the returned line number count for the main routine.

PZC

This function subprogram computes the probability of a parameter falling in a specific range for a Normal or Weibull distribution function. It uses a table lookup of probability for the Normal Distribution function.

The call to this subroutine is:

CALL PZC (XL, XU, AM, AS, WA, WB, WC, LD, M)

XL	-	is input lower limit value.
XU	-	is input upper limit value.
AM	-	is input distribution mean value.
AS	-	is input distribution standard deviation.
WA, WB, WC	-	is input Weibull distribution parameters if LD $>$ 0.
LD	-	is option LD $\leq$ 0 Normal distribution. LD $>$ 0 Weibull distribution.
M	-	is current or last table lookup indicator.

This subroutine uses the Normal distribution tables in common block 'CZ' entered in Subroutine CHISQ. Probabilities for the Weibull distribution are based on Equation 2-47.

RANGE

'RANGE' is used for histogram preparation. It computes a desireable cell definition using the range of the data and a desired number of cells. The number of cells will be equal to or greater than that specified depending upon the evenness of the cell width. Acceptable engineering divisions are used in selecting cell starting and ending values. The array must be in ascending order. If it is in descending order it is first rearranged to ascending order.

The call to this subroutine is:

CALL RANGE (X, N, XMAX, XMIN, DX, NDX, ERRTB)

X	-	is an input array of values in ascending or descending order.
N	-	is number of values in 'X' array.
XMAX	-	is calculated upper value of 'X' array.
XMIN	-	is calculated lowest value of 'X' array.
DX	-	is computed cell width for histrograms.
NDX	-	is the computed number of cells for the histrogram.
ERRTB	-	is an error signal generated. = 0 indicates no problems = 1 indicates a zero range for the 'X' table

RNDX

A pseudo random number generator for a Normal Distribution, N(0, 1). It uses as computer supplied uniform random number generator (RANF) to generate a number from zero to one. This is transformed to give the Random Normal Deviate (RXD) from the Normal distribution having zero mean and unity variance. The coding presented in this report also shows an alternate pseudo random number generator which can be used in place of RANF.

The call to this subroutine is:

CALL RNDX (JK)

JK	-	is the number of random normal deviates to be calculated.

The input seed 'K' and the generated random normal deviates 'RXD' are transferred through blank common.

RUNGE

This is the basic fourth-order RUNGE-KUTTA integration method which is used in conjunction with CALCU to integrate the trajectory equations.

The call to this subroutine is:

CALL RUNGE (L, I)

L	-	is the control parameter for the Runge-Kutta integration formulae.
I	-	is the counter for the number of passes made in the multi-step process of one integration step. It is set to zero after completion of a complete cycle.

TABGEN

In cases where a ballistic (gravity turn) trajectory is flown following booster ignition certain trajectory tables are estimated by this subroutine. It uses a fourth order RUNGE-KUTTA integration of the trajectory equations in subroutines CALCU and RUNGE. It requires initial conditions of flight path angle, dynamic pressure, velocity, predicted attitude error, and drag coefficient. Input tables of thrust and weight are used. After filling tables of dynamic pressure, velocity, altitude and flight path angle, it changes the input pitch attitude error table (TABLE 6) to pitch attitude using the newly calculated flight path angle as the reference attitude.

The call to this subroutine is:

CALL TABGEN (QO, VO, GAMO)

QO	-	is the input initial dynamic pressure (lbs/ft^2).
VO	-	is the input initial velocity (ft/sec).
GAMO	-	is the input initial flight path angle (degrees)

Output data is transferred via labeled common block 'DOUT'. Input data is transferred by common blocks 'DRH', 'DDI', and 'DDY'. This subroutine contains the data table of the logarithm of inverse atmospheric density versus altitude 'RHO' which is contained in common blocks 'DRH'.

TBLN

This is a single table lookup subroutine using linear interpolation between points. This subroutine requires separate arrays of abscissas and ordinates. The abscissas must be in ascending order.

The call to this subroutine is:

CALL TBLN (Y, X, T, A, NT, M)

Y	-	is the ordinate to be found.
X	-	is the given abscissa.
T	-	is the abscissa table.
A	-	is the corresponding ordinate table.
NT	-	is the number of values in each table.
M	-	is a current locator for the search of the table. 'M'must be greater than zero and less than or equal to 'NT'. M returns the current location found for the abscissa and should be used for the next lookup of the same table to reduce the search time.

TBLU

This is also a single table lookup. It is based on linear interpolation between points for a single array having alternating values of abscissas and ordinates. The abscissas must be in ascending order.

The call to this subroutine is:

CALL TBLU (NT, Y, X, T, M)

NT	-	number of values in table 'T' including abscissas and ordinates.
Y	-	is the ordinate to be found.
X	-	is the given abscissa.
T	-	is the table of alternating abscissas and ordinates.
M	-	is the table locator described under 'TBLN' above.

THEMIN

'THEMIN' computes the minimum acceleration for which one sided limit cycle motion can occur (Figure 3).

The call to this subroutine is:

CALL THEMIN (THEC, GR, DR, H, T1, T2, THMIN)

THEC	-	is the given control acceleration (rad/sec^2).
GR	-	is the rate to displacement gain ratio (K_R/K_D sec).
DR	-	is the deadband halfwidth (radians).
H	-	is the switching hysteresis fraction.
T1	-	is the turn-on time delay (seconds).
T2	-	is the turn-off time delay (seconds).
THMIN	-	is the computed disturbing angular acceleration at which the deadband will get crossed (rad/sec^2).

WBL

'WBL' is the main subroutine which computes the statistical parameters from an array of numbers. It computes the mean, standard deviation, skewness and kurtosis parameters as well as selected probability levels based on the Normal, Log-Normal and Weibull probability distribution functions. It also estimates a Level of Significance based on the Chi-Squared Goodness of Fit Test.

The call to this subroutine is:

CALL WBL (N, Y, NG, F)

N	-	is the number of values in the sample population.
Y	-	is the sample population array.
NG	-	is the number of cells to be used for the CHI-Squared Goodness of Fit Test.
F	-	is an array of 20 numbers containing the output information.

F(1) - is sample mean
F(2) - standard deviation
F(3) - skewness
F(4) - kurtosis
F(5) - mean of logarithm of values
F(6) - standard deviation of logarithm of values
F(7) - skewness of logarithm of values
F(8) - kurtosis of logarithm of values
F(9) - 0.995 probability level, 0.95 confidence level, for Normal Distribution
F(10) - predicted 0.995 probability level, 0.95 confidence level, based on Log-Normal distribution
F(11) - 'a' parameter for Weibull Distribution
F(12) - 'b' parameter for Weibull Distribution
F(13) - 'c' parameter for Weibull Distribution
F(14) - 0.5 probability level for Weibull Distribution
F(15) - 0.990 probability level for Weibull Distribution
F(16) - 0.995 probability level for Weibull Distribution
F(17) - 0.999 probability level for Weibull Distribution
F(18) - level of significance for Normal Distribution
F(19) - level of significance for Log-Normal Distribution
F(20) - level of significance for Weibull Distribution

3.4 Input Data Description

Input data is in fixed field format and includes fixed point, hollerith and floating point fields. Figure 7 presents a sample run input listing. Basic groups of input include the following:

1) one card of fixed point numbers including all of the run options, run number, number of random samples and number of boost phase integration steps,

2) two cards of Hollerith data describing the run for output heading,

3) initial random sequence integer for the pseudo random number generator,

4) moment of inertia and center of mass table,

5) list of single values of vehicle, mission and control system constants,

6) list of statistical means and standard deviations of random variables for the boost phase,

7) optional separate coast control variables,

8) tables of vehicle, trajectory time histories and wind versus altitude tables,

9) Optional vehicle and trajectory inputs replacing Group 8

3.4.1 Group 1 Input (Input Options)

The first card of input includes eleven fixed point constants in fields of five, right justified, starting in columns 1 through 5. These are:

Card Column	FORTRAN Variable	Description
1-5	NRUN	An arbitrary run number
6-10	IT	Number of random cases to be computed by the Monte Carlo procedure (current dimensions limit this to 1000 samples)
15	IO(1)	Output print option 1 Gives output information for each sample and the statistical distribution information 2 Gives only the statistical distribution information
20	IO(2)	2 Assumes the coast control and boost controls are the same 3 Coast control system uses different input than boost system (this requires additional input under Group 7)

Card Column	FORTRAN Variable		Description
25	IO(3)	1	Calculate boost fuel and coast time
		2	Calculate boost, coast and total fuel (If IO(2) = 3; retro time is computed based on input total fuel available in Group 5)
30	IO(4)	1	Deletes control system pitch and yaw filter delay time in coast after time specified in Group 5 input
		2	Control system filter delay used in boost and coast
34-35	IO(5)		Number of integration steps (up to 50) to be used in boost fuel consumption during web time (web time is specified in Group 5 data)
39-40	IO(6)		Number of integration steps to be used during booster motor tail off between web time and burnout time specified in Group 5 data
45	IO(7)		Separate coast control logic if IO(2) = 3,
		0	Coast roll motors used for yaw and roll
		1	Coast pitch and yaw motors are the same
50	IO(8)	0	Input all trajectory tables in Group 8
		1	Input Group 9 data instead of Group 8
55	IO(9)	0	Print histograms of fuel consumption
		1	No histogram output

3.4.2 Group 2 Title

Group 2 includes two cards of Hollerith arbitrary data for the user to describe the run. It includes only the first seventy two (72) columns on each card. This information is written on the first page of output of the run.

3.4.3 Group 3 Initial Random Number Seed

The fourth card of input is an integer number for the start of the pseudo-random number generator. It is located in the first eighteen (18) columns on the card and is right justified. On IBM machines having seven digit accuracy this should be changed to a seven digit integer (eg. 1234567) and a Format change would be required. This also requires the optional coding in the subroutine RNDX shown in the FORTRAN listing.

3.4.4 Group 4 Mass Properties

This group provides the transverse moment of inertia and center of mass station versus fraction of booster propellant consumed. It uses three points (0, 0.5 and 1.0) of propellant consumed to fit the data to a second order polynomial. The nine values are stored in array TABLE 1. Data is entered three to a card in three fields of 10 columns as follows,

Col. 1-10	11-20	21-30	values at
0.0	Iy (Slug-Ft^2)	X_{cg} (Sta. in.)	ignition
0.5	Iy	X_{cg}	50%
1.0	Iy	X_{cg}	burnout

3.4.5 Group 5 Single Constants

This group used on all runs consists of single valued constants. There are twenty-one cards in this group. Each card has a single value located in the first fifteen columns (Format E15.5). The first sixteen values are stored in the "A" array. These start with card eight.

Card No.	FORTRAN Variable	Symbol	Units	Description
8	A (1)	N	--	number of samples for correlating thrust misalignment initial value with slope
9	A (2)	$\rho_{\epsilon_{T_0}\dot{\epsilon}_T}$		correlation coefficient for pitch thrust misalignment
10	A (3)	$\rho_{\epsilon_{T_0}\dot{\epsilon}_T}$		correlation coefficient for yaw thrust misalignment
11	A (4)	X_c	inches	body station of control motors
12	A (5)	Z_c	inches	radial location of pitch and yaw control motors
13	A (6)	X_T	inches	body station of booster nozzle throat or action point of thrust misalignment
14	A (7)	R_c	inches	roll control motor moment arm from centerline
15	A (8)	cos λ	--	cosine of the pitch and yaw control motors forward cant angle

Card No.	FORTRAN Variable	Symbol	Units	Description
16	A (9)	$\sin\lambda$	--	sine of the pitch and yaw control motor forward cant angle
17	A (10)	t_f	seconds	time from ignition during which the filter delay is operating with the control system
18	A (11)	t_{coast}	seconds	coast time from burnout
19	A (12)	W_f	pounds	total control fuel available (used to compute retro time or coast time with appropriate options)
20	A (13)	t_{web}	seconds	booster web time or action time from ignition
21	A (14)	t_{bo}	seconds	booster burnout time after ignition
22	A (15)	W_{bo}	pounds	vehicle weight at booster burnout
23	A (16)	I_x	slug-ft^2	vehicle roll moment of inertia at burnout
24	CNAS	$C_{N_\alpha}S$	ft^2/rad	aerodynamic normal force coefficient slope
25	XCP	X_{cp}	inches	vehicle aerodynamic center of pressure station
26	GAMEl	γ_{e1}	degrees	standard deviation of initial flight path angle
27	ZEI	ζ_{e1}	degrees	standard deviation of initial azimuth
28	QFRAC	--	--	standard deviation of dynamic pressure ratio ($Q_{actual}/Q_{nominal}$)

3.4.6 Group 6 Random Variables

This group includes the mean and standard deviation of related boost system random variables. These are read in two values per card (format 2E15.5). This group starts with card 29 and continues through card 59.

Card No.	FORTRAN Variable	Symbol	Units	Description
29	ORM,ORS	Fp/Fc	--	boost pitch and yaw, control motor overshoot ratio mean and standard deviation for second order thrust response (Fig. 4) (if ORM 1.0, constant square wave thrust is assumed)
30	TPM,TPS	tp	seconds	pitch and yaw control motor time to peak overshoot thrust mean and standard deviation (Ignored if ORM = 1)
31	T2FM,TRFS	-	seconds	effective turn off delay time due to vehicle flexibility, mean and standard deviation (not used when filter is included)
32	B(1), B(2)	$\epsilon_{r_{op}}$	degrees	initial value of pitch thrust misalignment (mean and standard deviation)
33	B(3), B(4)	$\epsilon_{r_{oy}}$	degrees	initial value of yaw thrust misalignment (mean and standard deviation)
34	B(5), B(6)	$\dot{\epsilon}_{r_p}$	deg/sec	mean and standard deviation of time rate of change of pitch thrust misalignment
35	B(2), B(8)	$\dot{\epsilon}_{r_y}$	deg/sec	mean and standard deviation of time rate of change of yaw thrust misalignment
36	B(9), B(10)	I_{sp}	seconds	boost control motor specific impulse mean and standard deviation
37	B(11), B(12)	$\dot{\theta}_0$	deg/sec	mean and standard deviation of initial pitch rate
38	B(13), B(14)	θ_{e_0}	degrees	mean and standard deviation of initial pitch attitude error

Card No.	FORTRAN Variable	Symbol	Units	Description
39	B(15), B(16)	$\dot{\psi}_0$	deg/sec	mean and standard deviation of initial yaw rate
40	B(17), B(18)	ψ_{e_0}	degrees	mean and standard deviation of initial yaw attitude error
41	B(19), B(20)	RTI	ft-lb-sec	booster induced roll angular impulse mean and standard deviation
42	B(21), B(22)	ϵ_{JET}	degrees	mean and standard deviation of pitch and yaw control motor misalignment contributing to roll moment
43	B(23), B(24)	ζ_W	degrees	mean and standard deviation of wind direction azimuth
44	B(25), B(26)	ΔIy ΔXcg	slug-ft^2 inches	standard deviation of transverse moment of inertia and standard deviation of center of mass station in inches
45	C(1), C(2)	Δt_f	seconds	pitch and yaw filter delay time mean and standard deviation
46	C(3), C(4)	t_{rg}	seconds	mean and standard deviation of pitch and yaw gyro time delay
47	C(5), C(6)	t_{1m}	seconds	mean and standard deviation of pitch and yaw control motor turn-on delay time
48	C(7), C(8)	t_{2m}	seconds	mean and standard deviation of pitch and yaw control motor turn-off delay time
49	C(9), C(10)	K_R/K_D	seconds	boost pitch and yaw control system gain ratio mean and standard deviation
50	C(11), C(12)	d_b	degrees	boost pitch and yaw control deadband halfwidth mean and standard deviation
51	C(13), C(14)	H	--	mean and standard deviation of boost pitch and yaw control hysteresis fraction $(1-d_{off}/d_{on})$
52	C(15), C(16)	F_c	pounds	boost pitch and yaw control motor thrust mean and standard deviation

Card No.	FORTRAN Variable	Symbol	Units	Description
53	C(17), C(18)	t_{RG}	seconds	roll rate gyro delay time mean and standard deviation
54	C(19), C(20)	t_{1M}	seconds	boost roll motor turn-on delay time mean and standard deviation
55	C(21), C(22)	t_{2M}	seconds	boost roll motor turn-off delay time mean and standard deviation
56	C(23), C(24)	K_R/K_D	seconds	boost roll control gain ratio mean and standard deviation
57	C(25), C(26)	d_b	degrees	boost roll deadband halfwidth mean and standard deviation
58	C(27), C(28)	H	--	boost roll switching hysteresis (1 - d_{off}/d_{on}) mean and standard deviation
59	C(29), C(30)	F_c	pounds	boost roll control motor thrust mean and standard deviation

3.4.7 Group 7 Separate Coast System Variables (IO(2) = 3 Only)

This group is an optional input if a separately defined coast control system is used. This information must be input if IO(2) = 3 on the first card. This allows separate control motors, gains, time delays and a retro function during coast using the canted forward boost control motors. The first four cards are input one value per card with format E15.5. They are:

Card No.	FORTRAN Variable	Symbol	Units	Description
60	PTRC	$\Delta\dot{\theta}_c$	deg/sec	total pitch program rate changes during coast
61	YTRC	$\Delta\dot{\psi}_c$	deg/sec	total yaw program rate change during coast
62	TRETRO	t_{retro}	seconds	retro time required following coast with four boost pitch and yaw control motors

Card No.	FORTRAN Variable	Symbol	Units	Description
63	RETRSI	I_{sp}	seconds	retro motor specific impulse

In addition to these four cards, there are nine (9) additional cards of statistical control system values having two values per card (format 2E15.5). These are:

Card No.	FORTRAN Variable	Symbol	Units	Description
64	D(1), D(2)	d_c	degrees	coast system pitch and yaw deadband halfwidth, mean and standard deviation
65	D(3), D(4)	F_c	pounds	coast pitch control motor force, mean and standard deviation
66	D(5), D(6)	t_{1M}	seconds	coast pitch motor turn-on delay time, mean and standard deviation
67	D(7), D(8)	t_{2M}	seconds	coast pitch motor turn-off delay time, mean and standard deviation
68	D(9), D(10)	d_c	degrees	coast roll deadband halfwidth, mean and standard deviation
69	D(11), D(12)	F_c	pounds	coast roll motor thrust, mean and standard deviation
70	D(13), D(14)	t_{1M}	seconds	coast roll motor turn-on delay time, mean and standard deviation
71	D(15), D(16)	t_{2M}	seconds	coast roll motor turn-off delay time, mean and standard deviation
72	D(17), D(18)	I_{sp}	seconds	coast control specific impulse, mean and standard deviation

3.4.8 Group 8 Trajectory Tables IO(8) = 0

This group concludes the input data stream for a run. It includes tables of time and altitude histories. If IO(8) = 1 certain tables are deleted as described in Group 9 in the following paragraph. Each table is input in the same format. Preceding each table a card having the integer number of values in the table is located in columns 1 through 5, right justified (Format I5).

The values are entered alternating abscissas and ordinates in fields of ten columns. These are entered six (6) per card until the table is completed. Figure 7 is the input for the sample problem which shows this format. The format for the whole table is (I5/(6F10.3)). A description of the tables and their order is:

TABLE NAME	ORDINATE	UNITS	ABSCISSA	UNITS	DESCRIPTION
TABLE 1	Q	lbs/ft^2	t	sec	dynamic pressure versus time after ignition
TABLE 2	T	lbs	t	sec	booster nominal thrust versus time after ignition
TABLE 3	W_p	lbs	t	sec	booster propellant weight remaining versus time after ignition
TABLE 4	θ_c	deg	t	sec	pitch program attitude from local horizontal versus time after ignition
TABLE 5	V	ft/sec	t	sec	nominal velocity versus time after ignition
TABLE 6	γ_{PR}	degrees	t	sec	flight path angle from local horizontal versus time after ignition
TABLE 7	ζ_{PR}	degrees	t	sec	nominal azimuth versus time after ignition
TABLE 8	β_{NOM}	degrees	t	sec	nominal angle of sideslip versus time after ignition on an undisturbed trajectory
TABLE 9	V_{W_μ}	ft/sec	h	ft	mean value of wind velocity versus altitude above sea level
TABLE 10	V_{W_σ}	ft/sec	h	ft	standard deviation of wind velocity versus altitude above sea level
TABLE 11	h	feet	t	sec	altitude versus time after ignition

Each of the above tables is limited to ninety (90) values which is a maximum of forty-five (45) pairs of abscissas and ordinates.

3.4.9 Group 9 Trajectory Tables IO(8) = 1

For parametric studies the option to generate nominal trajectory parameters becomes useful. This option generates a gravity turn trajectory from other input data. With this option Group 9 data replaces Group 8 data. Figure 8 presents a sample input for the case. The first card includes four variables read in four fields of ten columns (format 8F10.3). These variables are:

FORTRAN VARIABLE	SYMBOL	UNITS	DESCRIPTION
QO	Q_o	lbs/ft^2	nominal dynamic pressure at ignition
VO	V_o	ft/sec	nominal velocity at ignition
GAMO	γ_o	degrees	nominal flight path angle at stage ignition
CDS	C_DS	ft^2	aerodynamic drag coefficient times reference area

Following this card seven tables are entered. Each table is preceded by a card containing the integer number of values in the table in a field of five (5) right justified (format I5). Following this card the table is entered in floating point numbers in fields of ten (10) columns, six (6) values per card. The format is (6F10.3). The order and description of these tables are as follows:

TABLE NAME	ORDINATE	UNITS	ABSCISSA	UNITS	DESCRIPTION
Table 2	T	lbs	t	sec	booster nominal thrust versus time after ignition
Table 3	W	lbs	t	sec	booster nominal thrust versus time after ignition
Table 4	$\theta_c-\gamma_{PR}$	degrees	t	sec	difference between nominal pitch attitude and flight path angle versus time after ignition
Table 7	ζ_{PR}	degrees	t	sec	predicted azimuth time history
Table 8	β_{NOM}	degrees	t	sec	nominal angle of sideslip versus time after ignition
Table 9	V_{W_μ}	ft/sec	h	feet	mean value of wind, velocity versus altitude
Table 10	V_{W_σ}	ft/sec	h	feet	standard deviation of wind velocity versus altitude

3.5 Output Description

All output is on a line printer. There are several options for the output which are selected by the run options presented in paragraph 3.4.1.

There are five basic parts to the output, two of which can be deleted by input option. These include:

1) printout of selected parameters from each random sample (IO(1) = 1), can be deleted if (IO(1) = 2),

2) printout of all fuel consumption values arranged in ascending order with associated sample population probability level (always output),

3) sample distribution statistical parameters, final random number generator seed and number of samples having deadband overshoot occurrances,

4) summary statistics and level of significance for Normal, Log-Normal and Weibull Distribution functions,

5) histograms of the fuel consumption (IO(9) = 0), can be omitted if (IO(9) = 1)

Details of these parts of the output are presented in the following subparagraphs.

3.5.1 Individual Sample Parameters

If the input option (IO(1) = 1), two lines of parameters from each Monte Carlo random sample case are printed out after each case. This option results in a relatively large amount of printout. A typical page of output of these parameters is presented in Figure 9. A description of each in the order of output is:

OUTPUT NAME	UNITS	DESCRIPTION
SMPL	--	an integer sequence of the Monte Carlo case number
CAPT IMP	lb-sec	staging "capture" transient impulse
ROLL TORQIMP	lb-sec	roll control motor impulse due to rocket booster induced roll torque (RTI)
BOOSTIMP	lb-sec	total control impulse required during boost phase
T(WEB)	sec	booster web time
T(TO)	sec	booster tail off time

OUTPUT NAME	UNITS	DESCRIPTION
BOOST FUEL	lbs	control fuel consumption during boost
ISP	sec	control fuel specific impulse
CST FUEL	lbs	control fuel consumption during coast (not including retro fuel)
FLOW RATE	lbs/sec	coast fuel consumption flow rate with boost system - filter in
DB RED TORQ FUEL	lbs	fuel consumption required for deadband reduction transient and pitch program rate changes during coast
FLOW RATE COAST	lbs/sec	fuel flow rate during coast
RETRO TIME	sec	retro time achieved with remaining fuel consumption after coast
NO. OF DB OVERSHOOTS BOOST P-Y ROLL CST P-Y		number of times deadband overshoot occured during boost in pitch or yaw, in the roll channel, and during coast in pitch or yaw
TOTAL FUEL	lbs	total fuel consumption including boost, coast and retro

When the coast time option is used, (IO(3) = 1), (TOTAL FUEL) and (COAST FUEL) is deleted and (COAST TIME) is output in seconds.

3.5.2 Discrete Probability Levels

Fuel consumption in boost and coast, total fuel consumption and under some options retro time or coast time is printed versus probability of occurrence after being arranged in ascending order. A sample output is presented in Figure 10.

3.5.3 Sample Distribution and Final Seed

This page of output is presented in Figure 11. It includes the computed mean, standard deviation and estimated 99.5 percent probability with 95 percent confidence level of fuel consumption.

The last value calculated of the pseudo random number generator seed is output. This can be used as a starting value if an additional run is to be made to increase the sample size with the least risk of repeating parts of the sequence generated in the previous run.

The total number of cases having exceeded the deadband overshoot criteria at least once is also output on this page. Differentiation between boost and coast phases is made as well as roll axes during boost. The deadband overshoot criteria is an indicator of a very poorly designed on-off control system since it approaches a 100 percent duty cycle.

3.5.4 Summary Statistics and Level of Significance

A page of statistical information is output for comparison of the sample population with known distributions. Figure 12 presents a typical example. Sample population mean, standard deviation, skewness and kurtosis parameters are output under Normal Distribution. The estimated upper 95 percent confidence level at the 99.5 percent probability level is based on a prediction if the distribution were truly Gaussian (which is usually not the case). Level of Significance is computed based on the Chi-Squared Goodness of Fit Test. The level of significance is output for each of the distributions. A higher level of significance generally indicates a better fit. However, histogram output should also be considered in the statistical analysis.

Under the Log-Normal Distribution the sample distribution parameters for the natural logarithm of the fuel consumption is shown. The fuel consumption at the upper 95 percent confidence level at 99.5 percent probability level predicted by the Log-Normal distribution is also shown in pounds. Note that the parameters are expressed as the logarithm but the 99.5 percent level is not the logarithm. Level of significance is also presented from the Chi-Squared Goodness of Fit Test.

Weibull Distribution parameters (a, b, c) are presented which are based on the sample population. Values of fuel consumption at several selected probability levels as predicted by the fit to a Weibull Distribution are also output. Level of Significance from a Chi-Squared Goodness of Fit Test to the ideal Weibull Distribution having these parameters is also output.

3.5.5 Histograms

Histograms of the sample populations of fuel consumption and retro times are an optional output. Samples of this output are presented in Figure 13. Each output histogram includes:

- Identification
- Total number of samples
- Minimum and maximum values
- Number of values in each cell printed numerically below each cell
- Numerical value of starting and end points of each cell printed under each cell
- Graphical display of each cell by number of stars or asterisks rising from the base

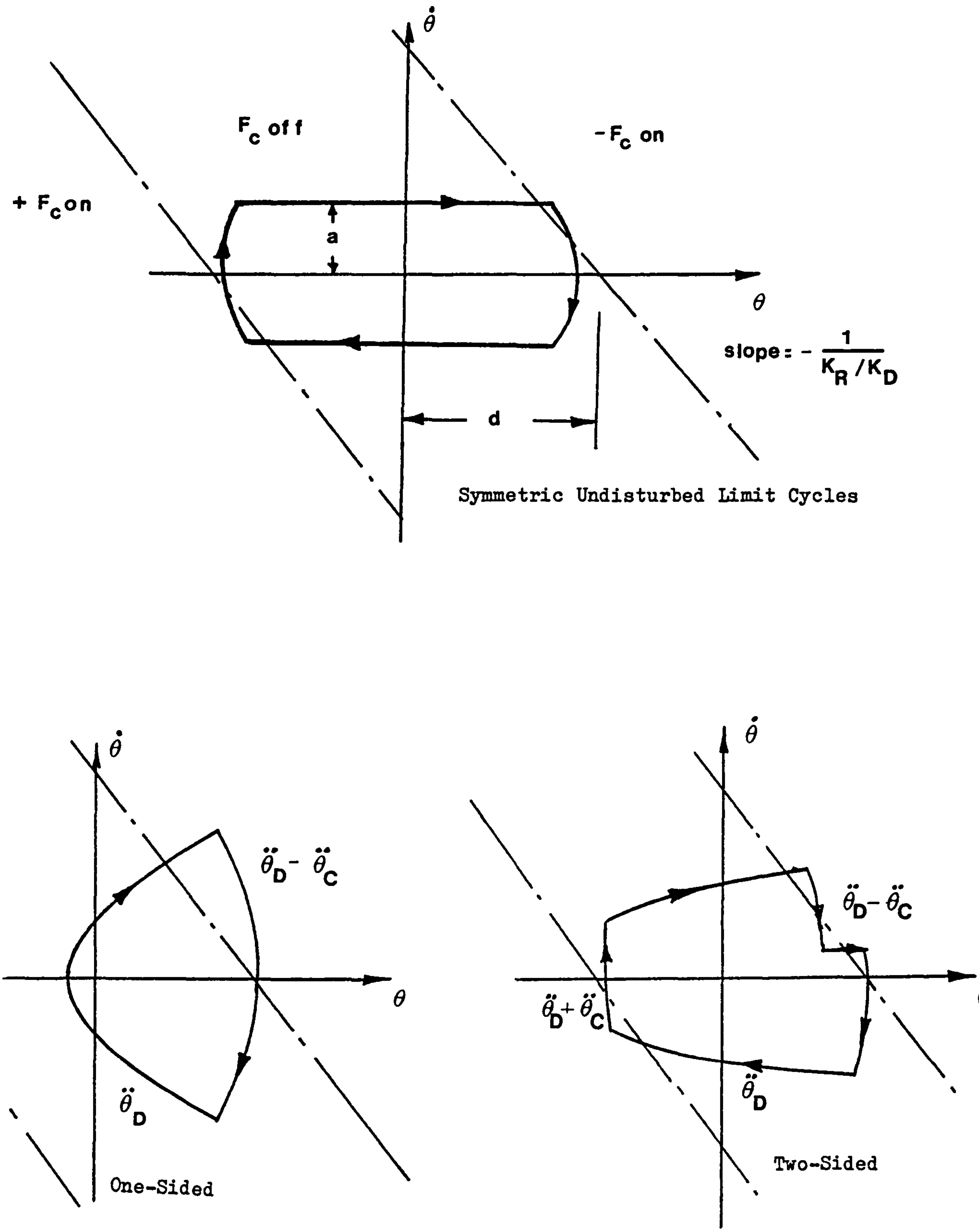
Maximum number of samples in a cell is 94 for display purposes. If a cell is completely filled the actual height can be obtained from the number printed at the base of the cell. The number of cells is automatically set at 30 or more over the range of data. In order to select aesthetically pleasing cell divisions the number of cells will vary somewhat and occassionally spill over more than a single page of output.

4.0 REFERENCES

(1) Glazier, M. N. and Knauber, R. N., "Scout Upper Stage Control Fuel Consumption Analysis - Revision C", Vought Corp. Report No. 23.256, 26 October 1971.

(2) Lindgren, B. W. and McElrath, G. W., "Introduction to Probability and Statistics." The Macmillan Company, New York, second printing 1960.

Figure 1
Control Phase Plane - Limit Cycles



Disturbed Limit Cycles

Figure 2
Trajectory and Angle Definitions

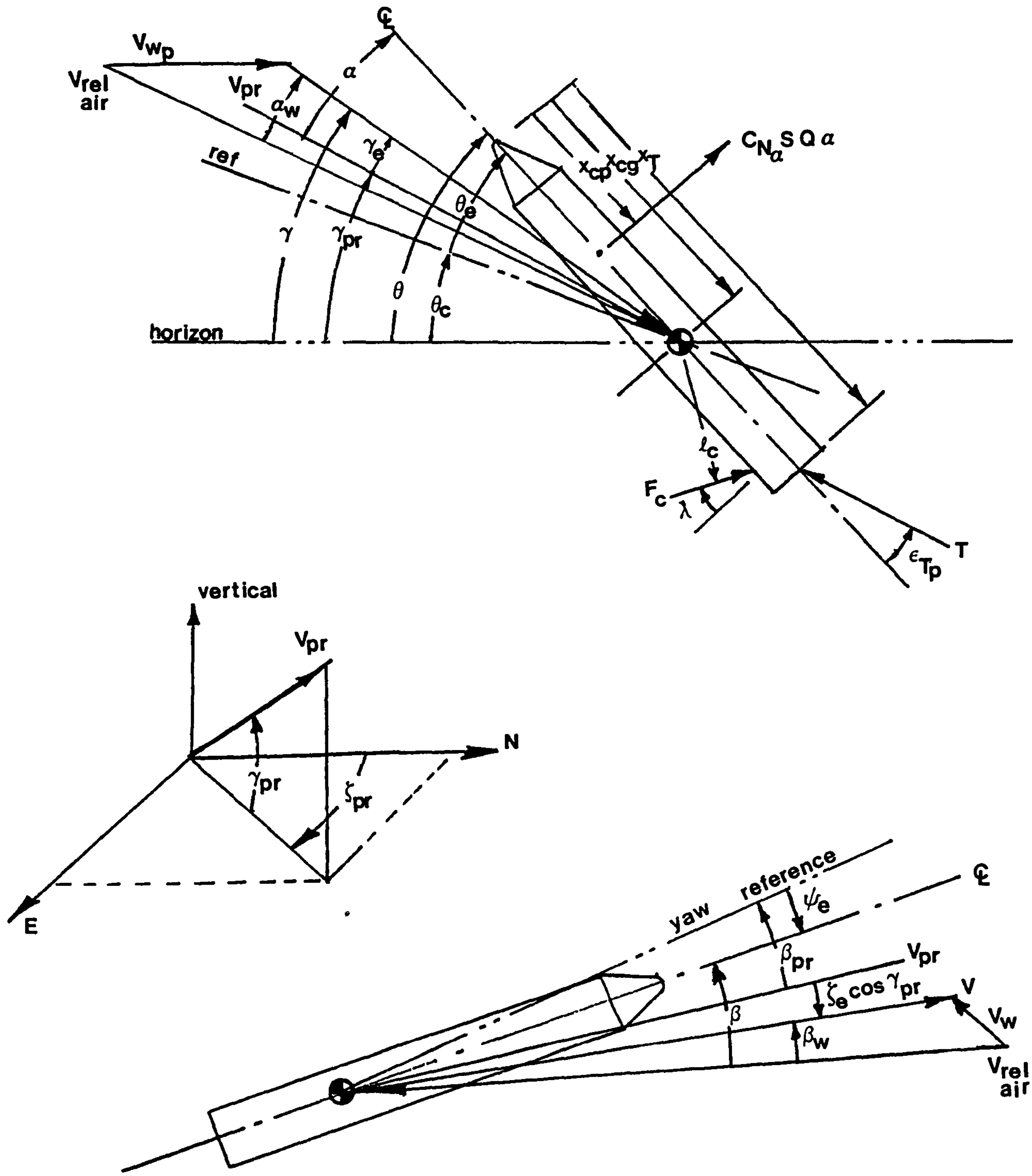
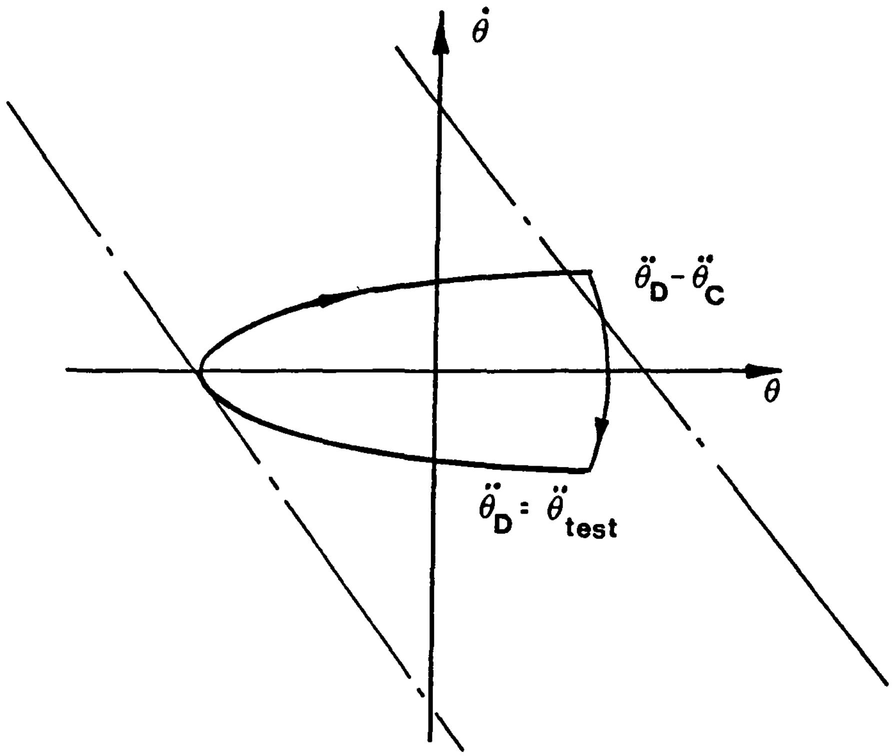


Figure 3
Minimum Acceleration for Deadband Crossing



$$\ddot{\theta}_{test} = \left| -\frac{E}{2D} \pm \sqrt{\left(\frac{E}{2D}\right)^2 + \frac{F}{D}} \right|$$

$$D = B - \left(K_R/K_D - T_1\right)\left(\frac{B-C}{A}\right) - 0.5\left(K_R/K_D\right)^2 - 0.5\left(\frac{B-C}{A}\right)^2$$

$$E = -2d - \left(K_R/K_D - T_1\right)\left(dH - C\ddot{\theta}_c\right)\Big/A - C\left(\frac{B-C}{A^2}\right)\ddot{\theta}_c$$

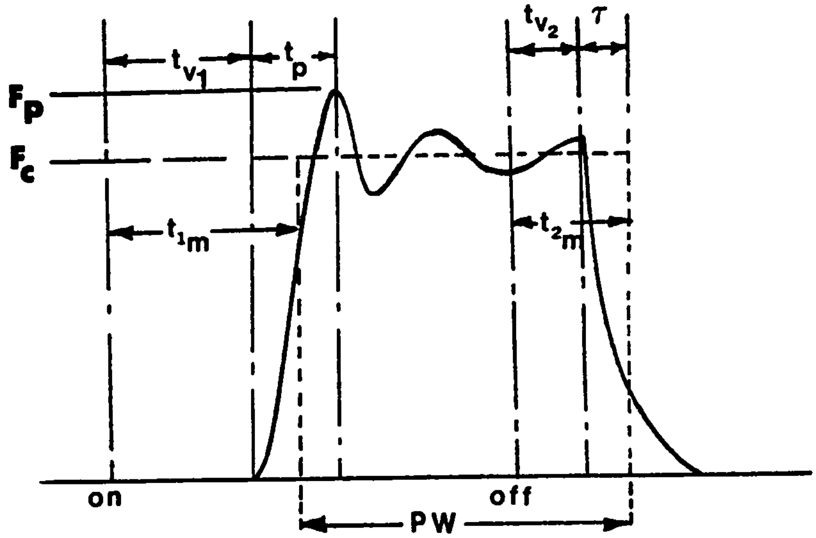
$$F = \frac{1}{A^2}\left[0.5\left(dH + C\ddot{\theta}_c\right)^2 + dH\left(B-C\right)\right]$$

$$A = 2K_R/K_D - T_1 - T_2$$

$$B = K_R/K_D \; T_1 - T_1^2/2$$

$$C = K_R/K_D \; T_2 - T_2^2/2$$

Figure 4
Control Motor Thrust Responses



$$t_{1m} = t_{v_1} \overset{A}{+} t_p\left(1 - \nu/2\right)\Big/2$$

$$\nu = \mathrm{Tan}^{-1}\left[\frac{\pi}{\ln\left(\frac{1}{F_p/F_c - 1}\right)}\right]$$

Figure 5
General Flow Chart of MAIN Routine

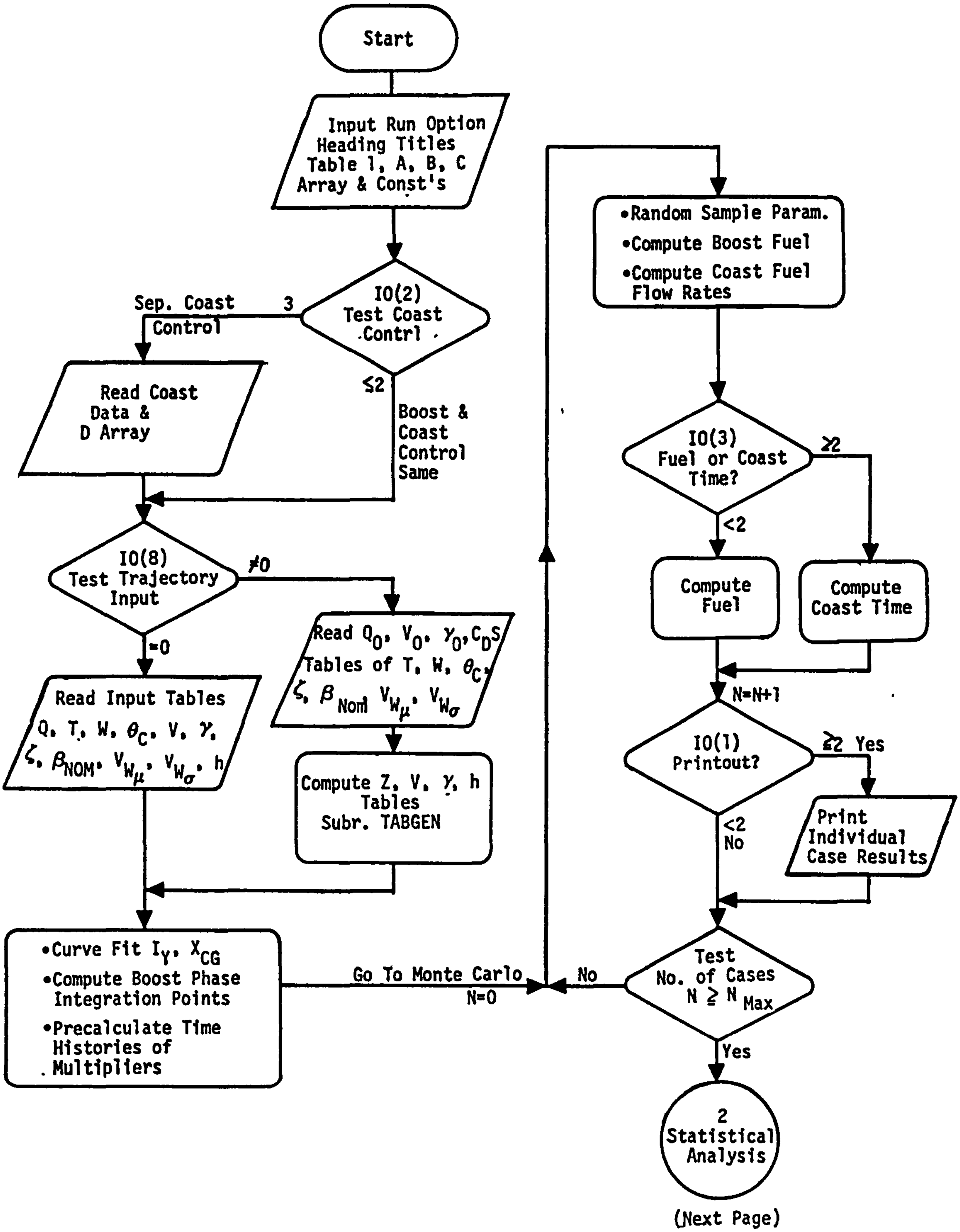


Figure 5 (Cont.)
General Flow Chart of MAIN Routine

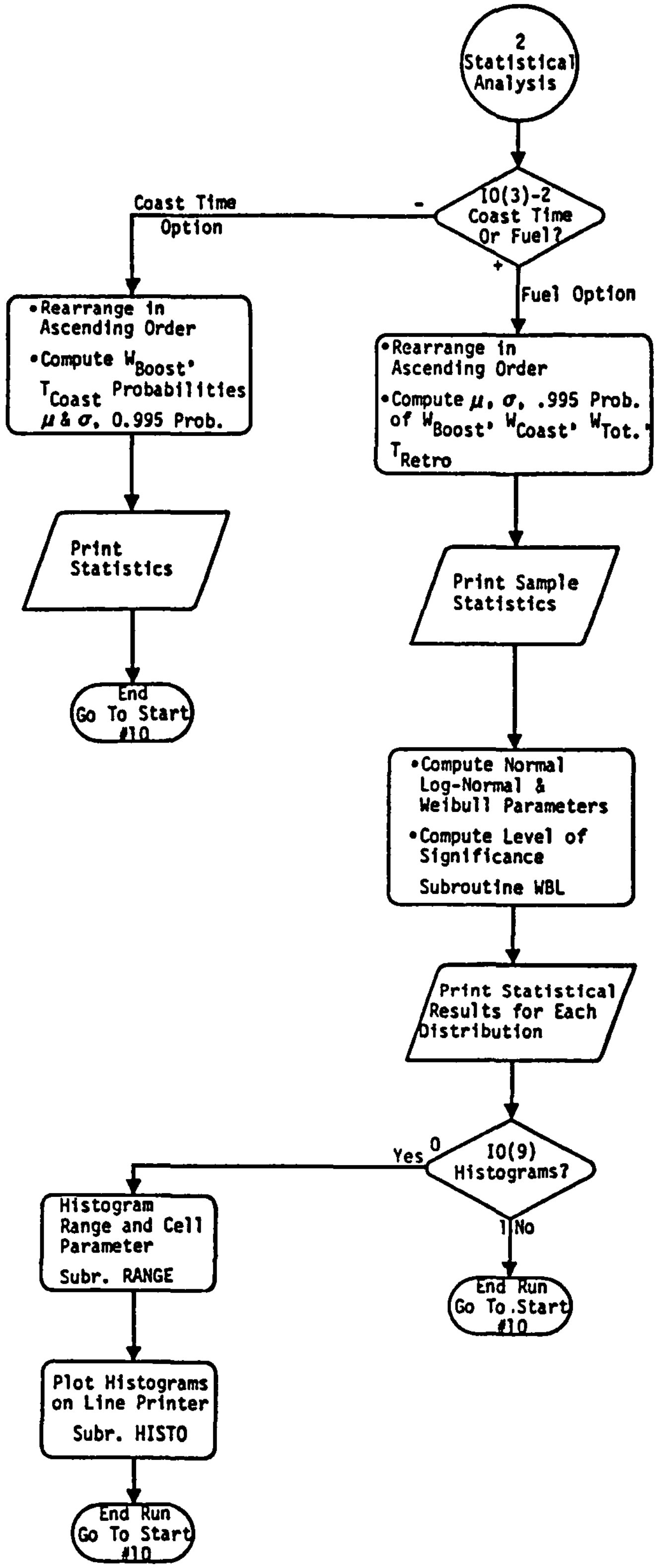


FIGURE 6

Program Subroutines and Common Interaction Map Subroutines

	Called Subroutines																	Common						
	ALTI	ASCEND	CALCU	CHISQ	CYCLE	HISTO	OVRF	PAGEHD	PZC	RANGE	RNDX	RUNGE	TABGEN	TBLN	TBLU	THEMIN	WBL	BLANK	DOUT	DDT	DRH	DDI	DDY	CZ
MAIN		X			X	X	X	X		X	X		X		X	X	X	X	X	X				
ALTI															X						X			
ASCEND																								
CALCU															X						X	X	X	
CHISQ									X					X										X
CYCLE																								
HISTO																								
OVRF																								
PAGEHD																								
PZC														X										X
RANGE																								
RNDX																		X						
RUNGE																							X	
TABGEN	X		X									X							X		X	X	X	
TBLN																								
TBLU																								
THEMIN																								
WBL				X											X									

Figure 7
Sample Problem Input IO(8) = 0

```
   1  499    2    3    2    1   12    4    1    0    0
SAMPLE PROBLEM SCOUT SECOND STAGE, FUEL OPTION, FILTER OUT IN
COAST,SEPARATE COAST CONTROL, NO YAW-ROLL MIXING  IO(8)=0
  625699253066457                  INITIAL RANDOM SEQ NO RANF
       0.  49241.45    282.07      IYY AND XCG @IGNITION (SLUG-
      0.5  41574.21    258.47                  @50% PROP  FT**2)
      1.0  27991.96    206.73                  @BURNOUT
           19.                     NO. OF SAMPLES FOR CORR COEFF
        -0.573                     CORR COEFF PITCH
        -0.756                     CORR COEFF YAW
        467.76                     CONTROL MOTOR STATION
         14.93                     CONTROL MOTOR LAT. LOC. (IN.)
        448.51                     BOOSTER NOZZLE THROAT STATION
         16.89                     ROLL CONTROL MOTOR ARM (IN.)
            1.                     COS OF CANT ANGLE (NO CANT)
            0.                     SIN OF CANT ANGLE (NO CANT)
         42.32                     FILTER IN TIME (SEC)
         34.92                     COAST TIME (SEC)
          167.                     CONTROL FUEL (LB)
         35.86                     BOOSTER WEB TIME (SEC)
         39.32                     BOOSTER BURNOUT TIME (SEC)
       6968.26                     WEIGHT B/O (LB)
        205.40                     IXX B/O (SLUG-FT**2)
         30.32                     CNAS FT2/RAD
         134.2                     XCP STATION
          0.30                     FLIGHT PATH ERROR (DEG)            SIGMA
          0.38                     AZIMUTH ERROR (DEG)                SIGMA
          0.12                     DYN.PRESS.RATIO(Q OVER QNOM)       SIGMA
          1.25          0.080      PITCH/YAW MOTOR OVERSHOOT RATIO    MEAN,SIGM
         0.019         0.0047      PITCH/YAW MOTOR TIME TO PEAK (SEC) MEAN,SIGM
         0.012          0.001      T2 FLEX FILTER OUT COAST (SEC)     MEAN,SIGM
        0.0816         0.0271      INITIAL ET PITCH (DEG)             MEAN,SIGM
        0.0098         0.0239      INITIAL ET YAW (DEG)               MEAN,SIGM
     -0.000193       0.000753      SLOPE OF ET PITCH (DEG/SEC)        MEAN,SIGM
```

FIGURE 7 (Continued)
Sample Problem Input IO(8)=0

-0.000302	0.000830	SLOPE OF ET YAW (DEG/SEC)	MEAN,SIGM
125.	0.	BOOST CONTROL ISP (SEC)	MEAN,SIGM
-0.098	0.326	INITIAL PITCH RATE (DEG/SEC)	MEAN,SIGM
0.292	0.340	INITIAL PITCH ERROR (DEG)	MEAN,SIGM
0.085	0.197	INITIAL YAW RATE (DEG/SEC)	MEAN,SIGM
0.0105	0.243	INITIAL YAW ERROR (DEG)	MEAN,SIGM
0.	0.	BOOSTER ROLL IMPULSE (FT-LB-SEC)	MEAN,SIGM
0.	0.3817	PITCH/YAW JET MISALIGNMENT (DEG)	MEAN,SIGM
259.0	20.0	WIND AZIMUTH (DEG)	MEAN,SIGM
0.0166	0.0033	IYY AND XCG STANDARD DEVIATION	SIGMA,SIGM
0.	5.	PITCH STATIC UNBALANCE (FT-LB)	MEAN,SIGM
0.	5.	YAW STATIC UNBALANCE (FT-LB)	MEAN,SIGM
0.0459	0.0034	FILTER DELAY TIME (SEC)	MEAN,SIGM
0.0093	0.0017	PITCH /YAW GYRO DELAY TIME (SEC)	MEAN,SIGM
0.0715	0.0088	PITCH/YAW MOTOR T1 (SEC)	MEAN,SIGM
0.0355	0.0052	PITCH/YAW MOTOR T2 (SEC)	MEAN,SIGM
0.5	0.01667	KR/KD (SEC)	MEAN,SIGM
0.802	0.0267	BOOST PITCH/YAW DEADBANDS (DEG)	MEAN,SIGM
0.035	0.0167	BOOST PITCH/YAW HYSTERESIS (FRACTION)	MEAN,SIGM
517.3	14.5	BOOST PITCH YAW CONTROL FORCE (LB)	MEAN,SIGM
0.0069	0.0008	ROLL RATE GYRO DELAY (SEC)	MEAN,SIGM
0.0251	0.0048	BOOST ROLL MOTOR T1 (SEC)	MEAN,SIGM
0.0162	0.0030	BOOST ROLL MOTOR T2 (SEC)	MEAN,SIGM
0.45	0.015	ROLL GAIN RATIO KR/KD (SEC)	MEAN,SIGM
1.432	0.0478	BOOST ROLL DEADBAND (DEG)	MEAN,SIGM
0.035	0.0167	ROLL HYSTERSIS (FRACTION)	MEAN,SIGM
45.45	1.68	BOOST ROLL MOTOR FORCE (LB)	MEAN,SIGM
0.45		PITCH PROGRAM RATE CHANGE (DEG/SEC)	
0.		YAW PROGRAM RATE CHANGE (DEG/SEC)	
0.		RETRO TIME (SEC)	
134.0		RETRO ISP (SEC)MUST BE NON-ZERO	
0.785	0.0267	PITCH YAW COAST DEADBANDS (DEG)	MEAN,SIGM
517.3	14.5	COAST PITCH MOTOR THRUST (LB)	MEAN,SIGM
0.0715	0.0088	COAST PITCH MOTOR T1 (SEC)	MEAN,SIGM

FIGURE 7 (Continued)
Sample Problem Input IO(8)=0

```
           0.0355          0.0052      COAST PITCH MOTOR T2 (SEC)              MEAN,SIG
            1.432          0.0478      COAST ROLL DEADBAND (DEG)               MEAN,SIG
            45.45            1.68      COAST ROLL MOTOR THRUST (LB)            MEAN,SIG
           0.0251          0.0048      ROLL MOTOR T1 (SEC)                     MEAN,SIG
           0.0162          0.0030      ROLL MOTOR T2 (SEC)                     MEAN,SIG
             125.              0.      COAST ISP (SEC)                         MEAN,SIG
   20      NOMINAL DYN. PRESS.(PSF) VS. TIME (SEC)
0.         99.92     3.84      76.65     8.84      56.36
13.84      42.73     18.84     33.18     23.84     25.49
28.84      18.20     33.84     11.95     38.84     5.89
43.84      2.28
   24      BOOSTER THRUST(LBS) VS. TIME (SEC)
0.         40000.    0.43      40643.    6.75      51961.4
12.53      61736.2   20.24     71254.0   25.54     73568.9
30.84      70482.1   34.5      69967.6   35.86     63794.0
36.77      10289.4   38.06     1029.0    39.32     0.
   12      BOOSTER PROPELLANT WEIGHT REMAINING (LBS) VS. TIME (SEC)
0.         8274.34   9.63      6548.78   20.24     4077.25
28.91      1844.78   35.65     188.52    39.32     0.
   18      NOMINAL PITCH ATTITUDE (DEG) VS. TIME(SEC)
0.         30.58     3.84      29.72     8.84      28.21
13.84      26.97     18.84     25.73     23.84     24.50
28.84      23.60     33.84     22.86     43.84     21.24
   12      VELOCITY (FT/SEC) VS. TIME (SEC)
0.         4394.     8.84      5183.     18.84     6666.
28.84      8849.     38.84     10897.    43.84     10839.
   18      NOMINAL FLIGHT PATH ANGLE(DEG) VS. TIME(SEC)
0.         31.05     3.84      29.75     8.84      28.18
13.84      26.79     18.84     25.59     23.84     24.53
28.84      23.62     33.84     22.86     43.84     21.58
    6      NOMINAL AZIMUTH(DEG) VS. TIME(SEC)
0.         182.79    18.84     182.842   43.84     182.90
    6      NOMINAL ANGLE OF SIDESLIP(DEG) VS. TIME (SEC)
0.         0.16      18.84     0.20      43.84     0.23
```

FIGURE 7 (Concluded)
Sample Problem Input IO(8)=0

```
    8      MEAN WIND VELOCITY(FT/SEC) VS. ALTITUDE(FEET)
120000.    120.      160000.   260.      220000.   310.
400000.    310.
    8      SIGMA WIND VELOCITY(FT/SEC) VS. ALTITUDE(FEET)
120000.    75.       160000.   100.      220000.   100.
400000.    100.
   10      ALTITUDE (FEET) VS. TIME (SEC)
0.         124795.   8.84      145378.   18.84     171644.
28.84      203371.   43.84     262430.
*EOR
```

Figure 8
Sample Problem Input IO(8) = 1

```
   1  799    2    3    2    1   12    4    1    1    0                     000001
 SAMPLE PROBLEM SCOUT SECOND STAGE, FUEL OPTION, FILTER OUT IN             000002
 COAST,SEPARATE COAST CONTROL, NO YAW-ROLL MIXING  IO(8)=1                 000003
27462569925306645 7                 INITIAL RANDOM SEQ NO RANF             000004
        0.  49241.45    282.07      IYY AND XCG @IGNITION (SLUG-           000005
        0.5 41574.21    258.47                  @50% PROP  FT**2)          000006
        1.0 27991.96    206.73                  @BURNOUT                   000007
            19.                     NO. OF SAMPLES FOR CORR COEFF          000008
          -0.573                    CORR COEFF PITCH                       000009
          -0.756                    CORR COEFF YAW                         000010
          467.76                    CONTROL MOTOR STATION                  000011
           14.93                    CONTROL MOTOR LAT. LOC. (IN.)          000012
          448.51                    BOOSTER NOZZLE THROAT STATION          000013
           16.89                    ROLL CONTROL MOTOR ARM (IN.)           000014
              1.                    COS OF CANT ANGLE (NO CANT)            000015
              0.                    SIN OF CANT ANGLE (NO CANT)            000016
           42.32                    FILTER IN TIME (SEC)                   000017
           34.92                    COAST TIME (SEC)                       000018
            167.                    CONTROL FUEL (LB)                      000019
           35.86                    T WEB (SEC)                            000020
           39.32                    T BURNOUT (SEC)                        000021
         6968.26                    WEIGHT B/O (LB)                        000022
          205.40                    IXX B/O (SLUG-FT**2)                   000023
           30.32                    CNAS FT2/RAD                           000024
           134.2                    XCP STATION                            000025
            0.30                    FLIGHT PATH ERROR (DEG)                000026
            0.38                    AZIMUTH ERROR (DEG)                    000027
            0.12                    Q FRACTION SIGMA                       000028
            1.25           0.080    PITCH/YAW MOTOR OVERSHOOT RATIO        000029
           0.019          0.0047    PITCH/YAW MOTOR TIME TO PEAK (SEC)     000030
           0.012           0.001    T2 FLEX FILTER OUT COAST (SEC)         000031
          0.0816          0.0271    INITIAL ET PITCH (DEG)                 000032
          0.0098          0.0239    INITIAL ET YAW (DEG)                   000033
       -0.000193        0.000753    SLOPE OF ET PITCH (DEG/SEC)            000034
```

FIGURE 8 (Continued)
Sample Problem Input IO(8)=1

-0.000302	0.000830	SLOPE OF ET YAW (DEG/SEC)	000035
125.	0.	BOOST CONTROL ISP (SEC)	000036
-0.098	0.326	INITIAL PITCH RATE (DEG/SEC)	000037
0.292	0.340	INITIAL PITCH ERROR (DEG)	000038
0.085	0.197	INITIAL YAW RATE (DEG/SEC)	000039
0.0105	0.243	INITIAL YAW ERROR (DEG)	000040
0.	0.	BOOSTER ROLL ANG. IMPULSE (FT-LB-SEC)	000041
0.	0.3817	PITCH/YAW JET MISALIGNMENT (DEG)	000042
259.0	20.0	WIND AZIMUTH (DEG)	000043
0.0166	0.0033	IYY AND XCG STANDARD DEVIATION	000044
0.	10.	PITCH STATIC UNBALANCE (FT-LB)	000045
0.	10.	YAW STATIC UNBALANCE (FT-LB)	000046
0.0459	0.0034	FILTER DELAY TIME (SEC)	000047
0.0093	0.0017	PITCH /YAW GYRO DELAY TIME (SEC)	000048
0.0715	0.0088	PITCH/YAW MOTOR T1 (SEC)	000049
0.0355	0.0052	PITCH/YAW MOTOR T2 (SEC)	000050
0.5	0.01667	KR/KD (SEC)	000051
0.802	0.0267	BOOST PITCH/YAW DEADBANDS (DEG)	000052
0.035	0.0167	BOOST PITCH/YAW HYSTERESIS (FRACTION)	000053
517.3	14.5	BOOST PITCH YAW CONTROL FORCE (LB)	000054
0.0069	0.0008	ROLL RATE GYRO DELAY (SEC)	000055
0.0251	0.0048	BOOST ROLL MOTOR T1 (SEC)	000056
0.0162	0.0030	BOOST ROLL MOTOR T2 (SEC)	000057
0.45	0.015	ROLL GAIN RATIO KR/KD (SEC)	000058
1.432	0.0478	BOOST ROLL DEADBAND (DEG)	000059
0.035	0.0167	ROLL HYSTERESIS (FRACTION)	000060
45.45	1.68	BOOST ROLL MOTOR FORCE (LB)	000061
0.45		PITCH PROGRAM RATE CHANGE (DEG/SEC)	000062
0.		YAW PROGRAM RATE CHANGE (DEG/SEC)	000063
1.25		RETRO TIME (SEC)	000064
165.		RETRO ISP (SEC)	000065
0.785	0.0267	PITCH YAW COAST DEADBANDS (DEG)	000066
517.3	14.5	COAST PITCH MOTOR THRUST (LB)	000067
0.0715	0.0088	COAST PITCH MOTOR T1 (SEC)	000068

FIGURE 8 (Concluded)
Sample Problem Input IO(8)=1

```
          0.0355         0.0052    COAST PITCH MOTOR T2 (SEC)                000069
           1.432         0.0478    COAST ROLL DEADBAND (DEG)                 000070
           45.45           1.68    COAST ROLL MOTOR THRUST (LB)              000071
          0.0251         0.0048    ROLL MOTOR T1 (SEC)                       000072
          0.0162         0.0030    ROLL MOTOR T2 (SEC)                       000073
            125.                   COAST ISP (SEC)                           000074
100.      4394.     31.05     4.2          INITIAL Q,V,GAMMA,CDS             000075
   24                BOOSTER THRUST TIME HISTORY                             000076
0.        40000.    0.43      40643.    6.75      51961.4                    000077
12.53     61736.2   20.24     71254.0   25.54     73568.9                    000078
30.84     70482.1   34.5      69967.6   35.86     63794.0                    000079
36.77     10289.4   38.06     1029.0    39.32     0.                         000080
   12     BOOSTER PROPELLANT WEIGHT REMAINING TIME HISTORY                   000081
0.        8274.34   9.63      6548.78   20.24     4077.25                    000082
28.91     1844.78   35.65     188.52    39.32     0.                         000083
   18                THETA - GAMMA VS. TIME                                  000084
0.        -0.47     3.84      -0.03     8.84      0.03                       000085
13.84     0.18      18.84     0.14      23.84     -0.03                      000086
28.84     -0.02     33.84     0.00      43.84     -0.34                      000087
    6               AZIMUTH VS. TIME                                         000088
0.        182.79    18.84     182.842   43.84     182.90                     000089
    6                BETA NOMINAL VS. TIME                                   000090
0.        0.16      18.84     0.20      43.84     0.23                       000091
    8               MEAN WIND VS. ALTITUDE                                   000092
120000.   120.      160000.   260.      220000.   310.                       000093
400000.   310.                                                               000094
    8               SIGMA WIND VS. ALTITUDE                                  000095
120000.   75.       160000.   100.      220000.   100.                       000096
400000.   100.                                                               000097
*EOR
```

Figure 9
Sample Output - Individual Cases - IO(1) = 1

RUN NO. 1 PAGE NO. 1
SAMPLE PROBLEM SCOUT SECOND STAGE, FUEL OPTION, FILTER OUT IN
COAST,SEPARATE COAST CONTROL, NO YAW-ROLL MIXING IO(1)=1

RUN NO. 1 PAGE NO. 2

SMPL	CAPT IMP (LB-SEC) CST FUEL (POUNDS	ROLL TORQ IMP(LB-SC) FLOW RATE FILTER IN	BOOST IMP (LB-SEC) DB RED TORQ FUEL(LBS)	T(WEB) (SEC) FLOW RATE COAST	T(TO) (SEC) RETRO TIME (SEC)	BOOST FUEL (LBS) NO. OF DB OVERSHOOTS BOOST P-Y	ROLL	ISP (SEC) CST P-Y	TOTAL FUEL (LBS)
1	5.4646E+02	0.	6.1790E+03	3.5860E+01	3.4600E+00	4.9432E+01		1.2500E+02	
	1.8943E+01	1.7264E+00	1.5804E+00	3.9416E-01	5.9620E+00	0	0	0	6.9956E+01
2	5.4880E+02	0.	4.9719E+03	3.5860E+01	3.4600E+00	3.9775E+01		1.2500E+02	
	2.1980E+01	1.4532E+00	1.5806E+00	5.0459E-01	6 5670E+00	0	0	0	6.3336E+01
3	5.5086E+02	0.	8.2154E+03	3.5860E+01	3.4600E+00	6.5723E+01		1.2500E+02	
	1.5582E+01	1.4637E+00	1.3367E+00	3.2048E-01	5.2454E+00	0	0	0	8.2642E+01
4	5.3516E+02	0.	7.4289E+03	3.5860E+01	3.4600E+00	5.9431E+01		1.2500E+02	
	1.9809E+01	1.6219E+00	1.5676E+00	4.2794E-01	5.2437E+00	0	0	0	8.0809E+01
5	4.6822E+02	0.	4.5942E+03	3.5860E+01	3.4600E+00	3.6753E+01		1.2500E+02	
	1.4933E+01	1.2776E+00	1.4241E+00	3.1786E-01	7.2418E+00	0	0	0	5.3110E+01
6	4.7494E+02	0.	6.7367E+03	3.5860E+01	3.4600E+00	5.3894E+01		1.2500E+02	
	2.1593E+01	1.5006E+00	1.5498E+00	4.8943E-01	5.4432E+00	0	0	0	7.7037E+01
7	4.4536E+02	0.	7.9478E+03	3.5860E+01	3.4600E+00	6.3582E+01		1.2500E+02	
	2.2065E+01	1.5464E+00	1.6535E+00	4.9901E-01	5.0415E+00	0	0	0	8.7301E+01
8	5.8024E+02	0.	7.3045E+03	3.5860E+01	3.4600E+00	5.8436E+01		1.2500E+02	
	1.7617E+01	1.3197E+00	1.5743E+00	3.9111E-01	5.6574E+00	0	0	0	7.7627E+01
9	4.1940E+02	0.	6.6580E+03	3.5860E+01	3.4600E+00	5.3264E+01		1.2500E+02	
	1.3521E+01	1.4828E+00	1.4131E+00	2.5981E-01	5.9898E+00	0	0	0	6.8198E+01
10	4.7358E+02	0.	5.4370E+03	3.5860E+01	3.4600E+00	4.3496E+01		1.2500E+02	
	1.7026E+01	1.2577E+00	1.4490E+00	3.7951E-01	6.4751E+00	0	0	0	6.1971E+01
11	5.4062E+02	0.	4.7588E+03	3.5860E+01	3.4600E+00	3.8071E+01		1.2500E+02	
	2.0306E+01	1.5617E+00	1.5992E+00	4.4735E-01	6.6078E+00	0	0	0	5.9976E+01
12	3.4429E+02	0.	5.2625E+03	3.5860E+01	3.4600E+00	4.2100E+01		1.2500E+02	
	2.1519E+01	1.1722E+00	1.6102E+00	5.1553E-01	6.4652E+00	0	0	0	6.5229E+01
13	6.0959E+02	0.	8.1023E+03	3.5860E+01	3.4600E+00	6.4819E+01		1.2500E+02	
	1.9598E+01	1.8900E+00	1.5984E+00	3.9885E-01	4.9586E+00	0	0	0	8.6015E+01
14	5.2931E+02	0.	5.0268E+03	3.5860E+01	3.4600E+00	4.0214E+01		1.2500E+02	
	2.2609E+01	1.5378E+00	1.6542E+00	5.1534E-01	6.2493E+00	0	0	0	6.4478E+01
15	4.5577E+02	0.	8.6983E+03	3.5860E+01	3.4600E+00	6.9586E+01		1.2500E+02	
	2.1728E+01	1.3950E+00	1.6270E+00	5.0236E-01	4.5541E+00	0	0	0	9.2941E+01

Figure 10
Sample Output - Discrete Probability

RUN NO. 1 PAGE NO. 1
SAMPLE PROBLEM SCOUT SECOND STAGE, FUEL OPTION, FILTER OUT IN
COAST,SEPARATE COAST CONTROL, NO YAW-ROLL MIXING IO(8)=0

RUN NO. 1 PAGE NO. 2

PROBABILITY	BOOST FUEL (POUNDS)	COAST FUEL (POUNDS)	RETRO TIME (SECONDS)	TOTAL FUEL (POUNDS)
.00200	22.729	11.891	7.8529	39.521
.00400	22.936	12.501	7.7257	43.684
.00600	24.861	12.974	7.7145	43.999
.00800	25.540	13.063	7.6578	44.486
.01000	26.821	13.068	7.6064	46.934
.01200	27.694	13.135	7.5769	47.270
.01400	28.001	13.521	7.4796	47.389
.01600	28.113	13.585	7.4234	48.100
.01800	29.158	13.699	7.3787	49.333
.02000	29.747	13.790	7.3498	49.605
.02200	29.908	13.816	7.3384	49.613
.02400	29.977	13.831	7.3149	49.775
.02600	30.128	13.908	7.3149	50.301
.02800	30.509	14.081	7.2684	50.362
.03000	30.728	14.214	7.2443	50.501
.03200	30.789	14.269	7.2418	50.506
.03400	31.044	14.380	7.2233	50.588
.03600	31.075	14.438	7.2182	50.635
.03800	31.220	14.688	7.1969	50.878
.04000	31.401	14.770	7.1951	50.890
.04200	31.560	14.787	7.1945	51.082
.04400	31.592	14.788	7.1917	52.219
.04600	32.336	14.814	7.1916	52.263
.04800	32.589	14.889	7.1857	52.338
.05000	32.621	14.894	7.1787	52.451
.05200	32.631	14.933	7.1600	52.632
.05400	32.892	14.943	7.1310	52.684
.05600	32.958	14.985	7.1260	52.758
.05880	32.985	15.018	7.1168	52.878
.06000	33.041	15.029	7.1086	52.889
.06200	33.046	15.042	7.1039	53.110
.06400	33.318	15.184	7.0836	53.213
.06600	33.516	15.255	7.0688	53.277
.06800	33.575	15.288	7.0657	53.459
.07000	33.615	15.332	7.0648	53.602
.07200	33.705	15.369	7.0565	53.786
.07400	33.994	15.397	7.0413	53.943
.07600	34.049	15.416	7.0124	54.014
.07800	34 125	15.429	7.0119	54.033
.08000	34.126	15.445	6.9678	54.088
.08200	34.196	15.469	6.9607	54.268
.08400	34.445	15.558	6.9453	54.348
.08600	34.635	15.582	6.9426	54.569
.08800	34.791	15.583	6.9342	54.574
.09000	34.815	15.602	6.9309	54.596
.09200	34.907	15.631	6.9213	54.607
.09400	34.927	15.668	6.9161	54.615
.09600	35.373	15.674	6.8917	54.845

FIGURE 10 (Continued)
Sample Output - Discrete Probability

RUN NO. 1 PAGE NO. 4

PROBABILITY	BOOST FUEL (POUNDS)	COAST FUEL (POUNDS)	RETRO TIME (SECONDS)	TOTAL FUEL (POUNDS)
.21400	39.907	17.418	6.5874	61.250
.21600	39.964	17.432	6.5818	61.314
.21800	39.994	17.464	6.5740	61.382
.22000	40.063	17.468	6.5670	61.446
.22200	40.185	17.485	6.5666	61.449
.22400	40.214	17.494	6.5665	61.453
.22600	40.214	17.502	6.5606	61.479
.22800	40.258	17.514	6.5529	61.537
.23000	40.269	17.553	6.5400	61.663
.23200	40.351	17.554	6.5394	61.676
.23400	40.476	17.567	6.5382	61.826
.23600	40.570	17.573	6.5342	61.830
.23800	40.629	17.590	6.5330	61.887
.24000	40.637	17.602	6.5262	61.896
.24200	40.654	17.608	6.5208	61.904
.24400	40.832	17.615	6.5168	61.925
.24600	40.845	17.617	6.5150	61.954
.24800	40.853	17.618	6.5145	61.971
.25000	40.948	17.621	6.5135	62.216
.25200	41.079	17.650	6.5103	62.230
.25400	41.175	17.686	6.5087	62.313
.25600	41.440	17.700	6.5080	62.314
.25800	41.510	17.703	6.5076	62.489
.26000	41.697	17.706	6.5062	62.701
.26200	41.792	17.725	6.5051	62.744
.26400	41.803	17.727	6.5021	62.846
.26600	41.805	17.728	6.4869	62.929
.26800	41.832	17.729	6.4861	62.969
.27000	41.871	17.746	6.4786	62.976
.27200	41.934	17.748	6.4772	63.046
.27400	41.982	17.754	6.4751	63.067
.27600	42.088	17.754	6.4729	63.138
.27800	42.100	17.755	6.4674	63.151
.28000	42.114	17.785	6.4652	63.216
.28200	42.226	17.836	6.4492	63.238
.28400	42.232	17.855	6.4452	63.336
.28600	42.305	17.907	6.4433	63.386
.28800	42.312	17.912	6.4404	63.405
.29000	42.342	17.966	6.4383	63.598
.29200	42.400	17.980	6.4272	63.604
.29400	42.429	18.004	6.4260	63.613
.29600	42.476	18.028	6.4244	63.645
.29800	42.477	18.039	6.4130	63.787
.30000	42.528	18.047	6.4120	63.854
.30200	42.578	18.062	6.4017	63.855
.30400	42.601	18.073	6.3978	63.948
.30600	42.627	18.129	6.3946	64.085
.30800	42.775	18.138	6.3920	64.117
.31000	42.841	18.144	6.3819	64.136
.31200	42.873	18.154	6.3777	64.182
.31400	43.036	18.154	6.3767	64.188
.31600	43.050	18.167	6.3755	64.244
.31800	43.126	18.169	6.3753	64.258

FIGURE 10 (Continued)
Sample Output - Discrete Probability

RUN NO. 1 PAGE NO. 5

PROBABILITY	BOOST FUEL (POUNDS)	COAST FUEL (POUNDS)	RETRO TIME (SECONDS)	TOTAL FUEL (POUNDS)
.32000	43.171	18.184	6.3741	64.296
.32200	43.388	18.187	6.3741	64.421
.32400	43.421	18.194	6.3654	64.478
.32600	43.496	18.225	6.3602	64.633
.32800	43.895	18.231	6.3567	64.706
.33000	43.917	18.264	6.3550	64.779
.33200	43.984	18.308	6.3451	64.779
.33400	44.205	18.327	6.3367	64.867
.33600	44.211	18.329	6.3316	64.868
.33800	44.231	18.335	6.3310	64.879
.34000	44.294	18.355	6.3298	64.908
.34200	44.320	18.364	6.3261	64.944
.34400	44.343	18.383	6.3198	64.973
.34600	44.371	18.384	6.3173	65.018
.34800	44.429	18.388	6.3138	65.095
.35000	44.473	18.390	6.3113	65.116
.35200	44.628	18.405	6.3029	65.118
.35400	44.679	18.407	6.3011	65.229
.35600	44.715	18.408	6.2877	65.259
.35800	44.869	18.408	6.2817	65.283
.36000	44.938	18.423	6.2786	65.527
.36200	44.962	18.427	6.2757	65.582
.36400	44.969	18.453	6.2754	65.588
.36600	45.046	18.466	6.2754	65.656
.36800	45.219	18.489	6.2746	65.744
.37000	45.255	18.492	6.2732	65.778
.37200	45.286	18.504	6.2582	65.781
.37400	45.307	18.511	6.2549	65.805
.37600	45.447	18.535	6.2493	65.833
.37800	45.485	18.549	6.2482	65.841
.38000	45.568	18.578	6.2460	65.939
.38200	45.645	18.585	6.2459	65.967
.38400	45.776	18.608	6.2446	66.279
.38600	45.811	18.615	6.2398	66.590
.38800	45.870	18.636	6.2376	66.627
.39000	45.927	18.665	6.2278	66.727
.39200	45.928	18.681	6.2221	66.772
.39400	46.014	18.688	6.2110	66.832
.39600	46.110	18.690	6.2088	66.875
.39800	46.214	18.698	6.2056	66.887
.40000	46.215	18.723	6.2047	66.924
.40200	46.283	18.729	6.2030	67.114
.40400	46.527	18.753	6.2018	67.149
.40600	46.559	18.766	6.1997	67.365
.40800	46.561	18.772	6.1935	67.549
.41000	46.657	18.775	6.1848	67.553
.41200	46 669	18.785	6.1736	67.576
.41400	46.733	18.790	6.1670	67.616
.41600	46.806	18.796	6.1568	67.851
.41800	46.832	18.803	6.1558	67.856
.42000	47.022	18.827	6.1527	67.914
.42200	47.040	18.848	6.1519	67.916
.42400	47.049	18.856	6.1459	68.108

FIGURE 10 (Continued)
Sample Output - Discrete Probability

RUN NO. 1 PAGE NO. 6

PROBABILITY	BOOST FUEL (POUNDS)	COAST FUEL (POUNDS)	RETRO TIME (SECONDS)	TOTAL FUEL (POUNDS)
.42600	47.095	18.896	6.1443	68.198
.42800	47.185	18.900	6.1407	68.308
.43000	47.266	18.943	6.1390	68.313
.43200	47.272	18.945	6.1380	68.357
.43400	47.331	18.946	6.1323	68.449
.43600	47.522	18.958	6.1306	68.491
.43800	47.525	18.984	6.1287	68.580
.44000	47.534	18.986	6.1262	68.636
.44200	47.545	18.987	6.1247	68.640
.44400	47.654	19.018	6.1187	68.849
.44600	47.774	19.019	6.1134	68.993
.44800	47.831	19.049	6.1110	69.006
.45000	47.910	19.052	6.1051	69.195
.45200	47.958	19.075	6.1017	69.242
.45400	48.006	19.084	6.0946	69.356
.45600	48.034	19.091	6.0903	69.384
.45800	48.235	19.099	6.0830	69.442
.46000	48.266	19.102	6.0754	69.506
.46200	48.321	19.209	6.0613	69.531
.46400	48.329	19.234	6.0591	69.569
.46600	48.337	19.248	6.0507	69.721
.46800	48.435	19.274	6.0472	69.746
.47000	48.446	19.287	6.0455	69.803
.47200	48.541	19.292	6.0444	69.807
.47400	48.590	19.296	6.0438	69.819
.47600	48.710	19.306	6.0405	69.956
.47800	48.765	19.316	6.0293	69.969
.48000	48.769	19.321	6.0285	69.978
.48200	48.830	19.328	6.0268	70.002
.48400	48.835	19.355	6.0256	70.018
.48600	48.835	19.355	6.0243	70.083
.48800	48.870	19.433	6.0231	70.144
.49000	48.872	19.454	6.0207	70.260
.49200	48.984	19.458	6.0134	70.263
.49400	49.116	19.463	6.0107	70.303
.49600	49.168	19.476	6.0077	70.309
.49800	49.172	19.482	6.0055	70.331
.50000	49.188	19.500	5.9998	70.342
.50200	49.201	19.521	5.9969	70.379
.50400	49.432	19.555	5.9936	70.422
.50600	49.435	19.558	5.9898	70.453
.50800	49.492	19.564	5.9888	70.547
.51000	49.506	19.583	5.9788	70.599
.51200	49.534	19.589	5.9738	70.643
.51400	49.585	19.598	5.9620	70.650
.51600	49.601	19.600	5.9617	70.836
.51800	49.676	19.602	5.9602	70.856
.52000	49.753	19.607	5.9569	70.920
.52200	49.796	19.621	5.9568	70.935
.52400	49.963	19.631	5.9556	71.042
.52600	50.000	19.659	5.9538	71.127
.52800	50.010	19.668	5.9483	71.148
.53000	50.094	19.688	5.9440	71.161

FIGURE 10 (Continued)
Sample Output - Discrete Probability

RUN NO. 1 PAGE NO. 7

PROBABILITY	BOOST FUEL (POUNDS)	COAST FUEL (POUNDS)	RETRO TIME (SECONDS)	TOTAL FUEL (POUNDS)
.53200	50.112	19.779	5.9369	71.219
.53400	50.178	19.787	5.9324	71.220
.53600	50.178	19.789	5.9304	71.257
.53800	50.215	19.809	5.9277	71.355
.54000	50.221	19.819	5.9274	71.357
.54200	50.234	19.827	5.9217	71.387
.54400	50.349	19.832	5.9212	71.451
.54600	50.424	19.835	5.9181	71.463
.54800	50.494	19.839	5.9160	71.559
.55000	50.494	19.870	5.9067	71.641
.55200	50.601	19.880	5.9060	71.672
.55400	50.791	19.916	5.8960	71.770
.55600	50.965	19.948	5.8929	71.945
.55800	51.005	19.956	5.8915	71.982
.56000	51.117	19.974	5.8840	71.994
.56200	51.182	19.987	5.8829	72.079
.56400	51.263	20.004	5.8825	72.273
.56600	51.297	20.020	5.8770	72.298
.56800	51.316	20.032	5.8722	72.299
.57000	51.392	20.057	5.8647	72.312
.57200	51.569	20.093	5.8637	72.428
.57400	51.574	20.122	5.8626	72.453
.57600	51.593	20.129	5.8583	72.518
.57800	51.622	20.130	5.8541	72.549
.58000	51.671	20.167	5.8528	72.613
.58200	51.749	20.173	5.8508	72.757
.58400	51.858	20.182	5.8500	72.759
.58600	52.034	20.202	5.8487	72.783
.58800	52.036	20.210	5.8464	72.793
.59000	52.052	20.227	5.8451	72.796
.59200	52.146	20.269	5.8444	72.797
.59400	52.219	20.295	5.8345	72.890
.59600	52.260	20.296	5.8296	72.956
.59800	52.270	20.296	5.8291	73.001
.60000	52.299	20.306	5.8202	73.027
.60200	52.358	20.323	5.8199	73.221
.60400	52.364	20.341	5.8024	73.359
.60600	52.449	20.367	5.7955	73.362
.60800	52.580	20.376	5.7951	73.367
.61000	52.606	20.421	5.7934	73.437
.61200	52.609	20.435	5.7917	73.603
.61400	52.652	20.442	5.7913	73.658
.61600	52.705	20.470	5.7909	73.693
.61800	52.711	20.470	5.7898	73.713
.62000	52.748	20.514	5.7882	73.723
.62200	52.754	20.518	5.7789	73.797
.62400	52.760	20.567	5.7740	73.808
.62600	52.764	20.576	5.7736	73.911
.62800	53.038	20.577	5.7727	73.916
.63000	53.048	20.584	5.7558	73.916
.63200	53.077	20.591	5.7548	73.966
.63400	53.090	20.606	5.7527	73.980
.63600	53.090	20.617	5.7440	74.136

FIGURE 10 (Continued)
Sample Output - Discrete Probability

RUN NO. 1 PAGE NO. 8

PROBABILITY	BOOST FUEL (POUNDS)	COAST FUEL (POUNDS)	RETRO TIME (SECONDS)	TOTAL FUEL (POUNDS)
.63800	53.097	20.626	5.7361	74.184
.64000	53.189	20.653	5.7294	74.309
.64200	53.193	20.656	5.7271	74.446
.64400	53.241	20.692	5.7243	74.514
.64600	53.264	20.738	5.7239	74.521
.64800	53.284	20.740	5.7237	74.540
.65000	53.363	20.745	5.7235	74.576
.65200	53.367	20.777	5.7175	74.593
.65400	53.433	20.783	5.7170	74.855
.65600	53.479	20.786	5.7167	74.978
.65800	53.490	20.790	5.7130	74.985
.66000	53.654	20.798	5.7055	74.986
.66200	53.703	20.826	5.7024	75.333
.66400	53.712	20.831	5.6995	75.345
.66600	53.737	20.831	5.6959	75.503
.66800	53.847	20.835	5.6846	75.667
.67000	53.894	20.856	5.6665	75.667
.67200	53.952	20.893	5.6574	75.683
.67400	53.957	20.902	5.6522	75.782
.67600	54.207	20.923	5.6488	75.786
.67800	54.249	20.925	5.6453	75.798
.68000	54.258	20.926	5.6299	75.944
.68200	54.260	20.950	5.6232	76.181
.68400	54.395	20.952	5.6203	76.199
.68600	54.670	20.958	5.6190	76.259
.68800	54.688	20.962	5.6088	76.262
.69000	54.712	20.996	5.6075	76.296
.69200	54.724	20.996	5.6068	76.507
.69400	54.778	21.004	5.6034	76.513
.69600	55.158	21.018	5.6012	76.528
.69800	55.360	21.050	5.6011	76.569
.70000	55.501	21.063	5.6000	76.659
.70200	55.543	21.066	5.5975	76.856
.70400	55.575	21.099	5.5908	77.037
.70600	55.589	21.101	5.5865	77.050
.70800	55.729	21.103	5.5662	77.139
.71000	55.782	21.113	5.5640	77.147
.71200	55.791	21.191	5.5612	77.187
.71400	55.830	21.207	5.5575	77.277
.71600	56.070	21.216	5.5550	77.397
.71800	56.189	21.229	5.5491	77.420
.72000	56.274	21.231	5.5472	77.576
.72200	56.355	21.254	5.5467	77.627
.72400	56.449	21.307	5.5390	77.706
.72600	56.484	21.326	5.5162	77.797
.72800	56.585	21.334	5.5137	77.799
.73000	56.655	21.365	5.5117	77.902
.73200	56.907	21.366	5.4968	77.947
.73400	56.934	21.371	5.4824	78.102
.73600	57.041	21.371	5.4806	78.447
.73800	57.149	21.448	5.4665	78.452
.74000	57.191	21.460	5.4653	78.570
.74200	57.308	21.467	5.4591	78.581

FIGURE 10 (Continued)
Sample Output - Discrete Probability

RUN NO. 1 PAGE NO. 10

PROBABILITY	BOOST FUEL (POUNDS)	COAST FUEL (POUNDS)	RETRO TIME (SECONDS)	TOTAL FUEL (POUNDS)
.85000	62.665	22.609	5.1219	84.236
.85200	63.013	22.650	5.1071	84.413
.85400	63.188	22.654	5.0959	84.601
.85600	63.270	22.663	5.0945	84.678
.85800	63.337	22.692	5.0834	84.767
.86000	63.506	22.801	5.0735	84.924
.86200	63.582	22.802	5.0699	85.190
.86400	63.624	22.951	5.0655	85.190
.86600	63.799	22.982	5.0541	85.192
.86800	63.813	23.014	5.0486	85.271
.87000	63.826	23.070	5.0468	85.417
.87200	63.930	23.077	5.0453	85.481
.87400	63.937	23.093	5.0415	85.504
.87600	64.092	23.176	5.0198	85.568
.87800	64.117	23.201	5.0158	85.699
.88000	64.150	23.322	5.0147	85.751
.88200	64.245	23.331	5.0141	85.790
.88400	64.344	23.413	5.0107	86.015
.88600	64.380	23.428	5.0060	86.266
.88800	64.668	23.474	5.0052	86.336
.89000	64.722	23.482	4.9907	86.846
.89200	64.724	23.521	4.9804	86.867
.89400	64.819	23.577	4.9651	87.128
.89600	64.869	23.641	4.9637	87.180
.89800	64.872	23.791	4.9586	87.249
.90000	64.875	23.801	4.9474	87.301
.90200	65.005	23.815	4.9413	87.312
.90400	65.069	23.831	4.9369	87.683
.90600	65.277	23.862	4.9348	87.966
.90800	65.661	23.874	4.9287	87.997
.91000	65.723	23.877	4.9129	88.032
.91200	65.825	23.894	4.9122	88.115
.91400	65.828	23.916	4.8993	88.206
.91600	66.388	23.936	4.8838	88.279
.91800	66.459	24.061	4.8807	88.403
.92000	66.622	24.101	4.8519	88.424
.92200	66.632	24.128	4.8263	88.505
.92400	67.039	24.165	4.8256	88.575
.92600	67.070	24.168	4.8201	88.689
.92800	67.523	24.258	4.8171	88.695
.93000	67.777	24.644	4.7769	88.942
.93200	67.874	24.648	4.7689	89.188
.93400	68.122	24.660	4.7554	89.804
.93600	68.917	24.708	4.7533	90.211
.93800	69.023	24.759	4.7531	90.608
.94000	69.147	24.775	4.7311	90.716
.94200	69.174	24.808	4.7290	90.846
.94400	69.290	24.829	4.7185	90.960
.94600	69.449	24.890	4.7021	91.055
.94800	69.573	24.891	4.6766	91.302
.95000	69.586	24.943	4.6613	91.540
.95200	70.021	24.943	4.6002	91.644
.95400	70.136	24.959	4.5862	91.754

FIGURE 10 (Concluded)
Sample Output - Discrete Probability

RUN NO. 1 PAGE NO. 11

PROBABILITY	BOOST FUEL (POUNDS)	COAST FUEL (POUNDS)	RETRO TIME (SECONDS)	TOTAL FUEL (POUNDS)
.95600	70.160	25.029	4.5736	92.110
.95800	70.372	25.107	4.5541	92.238
.96000	70.547	25.268	4.5511	92.941
.96200	71.412	25.312	4.5382	93.462
.96400	71.468	25.530	4.4708	93.953
.96600	71.545	25.570	4.4349	94.409
.96800	71.700	25.681	4.3756	95.466
.97000	72.882	25.694	4.3737	95.693
.97200	73.257	25.695	4.3540	96.082
.97400	73.411	25.698	4.3376	96.688
.97600	73.417	25.798	4.3165	96.732
.97800	73.968	26.164	4.2579	97.255
.98000	74.278	26.615	4.2546	97.645
.98200	74.386	26.666	4.2486	99.132
.98400	76.124	26.726	4.1131	99.869
.98600	77.220	26.766	4.1107	100.913
.98800	77.593	26.874	3.9945	101.108
.99000	77.897	28.161	3.9288	102.675
.99200	78.030	28.779	3.9255	102.800
.99400	78.164	28.882	3.7219	106.619
.99600	85.715	30.642	3.5038	109.539
.99800	88.123	30.970	3.3252	113.315

Figure 11
Output Page of Sample Statistical Data

RUN NO. 1 PAGE NO.

SAMPLE PROBLEM SCOUT SECOND STAGE, FUEL OPTION, FILTER OUT IN
COAST,SEPARATE COAST CONTROL, NO YAW-ROLL MIXING IO(8)=0

	BOOST FUEL	COAST FUEL	RETRO TIME	TOTAL FUEL
MEAN	49.783	19.660	5.9572	70.988
STD. DEVIATION	11.490	3.029	.7685	12.132
0.995 PROB 0.95 CONFID	88.179	31.395	3.3356	112.182

FINAL VALUE OF RANDOM SEQUENCE INTEGER = 274469945168434565

NO. OF SAMPLES WITH DEADBAND OVERSHOOT

BOOST(PITCH AND YAW) = 0

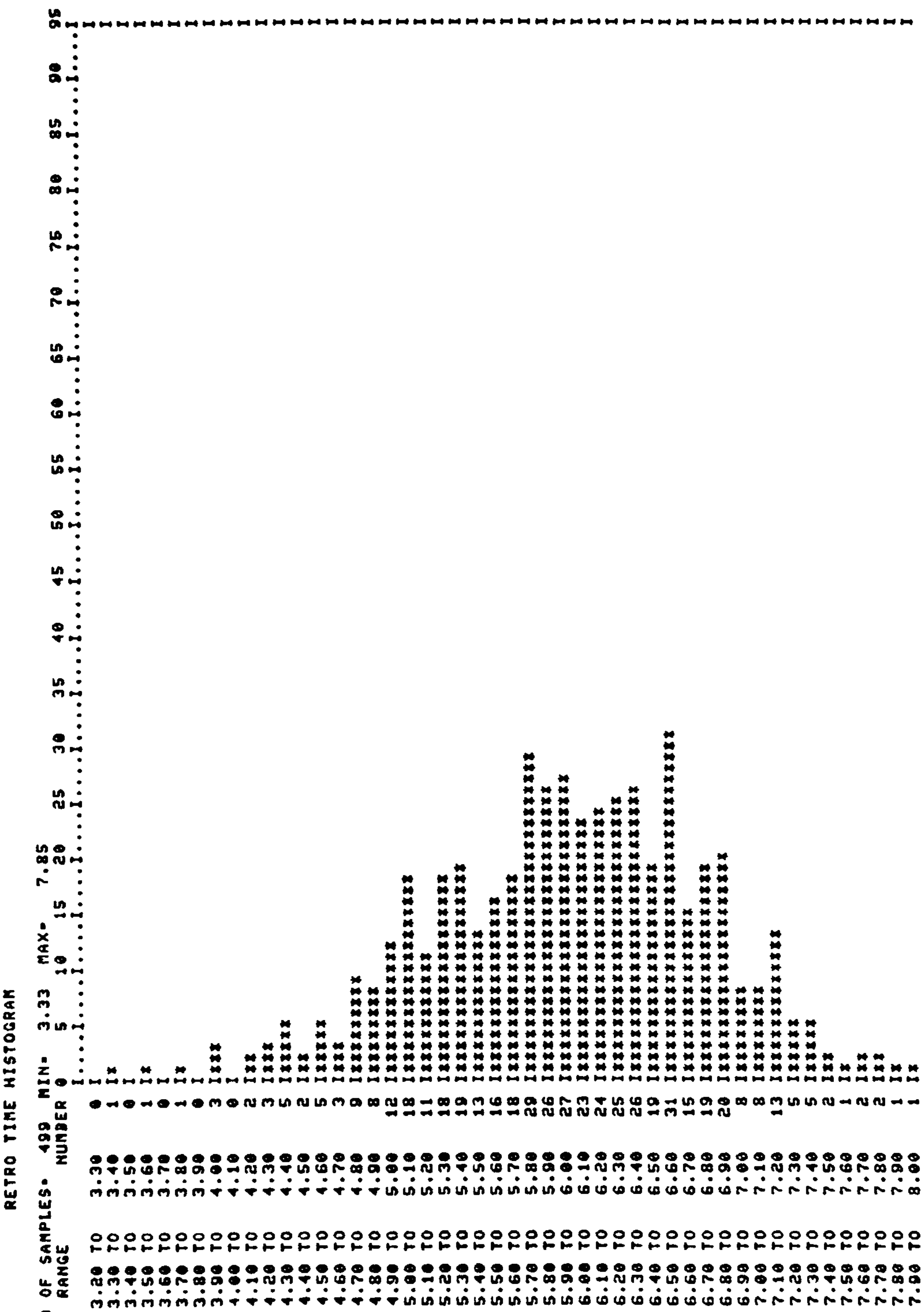
(ROLL) = 0

COAST = 0

Figure 12
Summary Statistics and Level of Significance

DISTRIBUTION FUNCTION FIT	BOOST	COAST	TOTAL
NORMAL DISTRIBUTION			
MEAN	49.783	19.660	70.988
STANDARD DEV	11.478	3.026	12.120
SKEWNESS	.302	.363	.342
KURTOSIS	2.744	3.408	2.987
0.995 PROB 0.95 CONF	81.378	27.990	104.350
LEVEL OF SIGNIFICNCE	.035	.044	.014
LOG NORMAL DISTRIBUTION (VALUES OF LOG)			
MEAN	3.880	2.967	4.248
STANDARD DEV	.236	.154	.172
SKEWNESS	-.275	-.134	-.125
KURTOSIS	2.792	3.142	2.858
0.995 PROB 0.95 CONF	92.777	29.722	112.184
LEVEL OF SIGNIFICNCE	.107	.756	.516
WEIBULL DISTRIBUTION			
PARAMETERS A	21.6359	12.5937	42.2023
B	31.6198	7.9491	32.3661
C	2.6618	2.5267	2.5726
PROBABILITY 0.5000	49.201	19.473	70.284
0.9900	77.734	27.136	100.777
0.9950	80.801	27.974	104.092
0.9990	86.965	29.667	110.776
LEVEL OF SIGNIFICANCE	.637	.003	.293

Figure 13
Histogram Output



```
          BOOST FUEL CONSUMPTION HISTOGRAM

NO OF SAMPLES=  499  MIN= 22.73  MAX=  88.12
   RANGE      NUMBER 0    5    10   15   20   25   30   35   40   45   50   55   60   65   70   75   80   85   90   95
                     I....I....I....I....I....I....I....I....I....I....I....I....I....I....I....I....I....I....I....I
20.00 TO  22.00    0 I                                                                                              I
22.00 TO  24.00    2 I**                                                                                            I
24.00 TO  26.00    2 I**                                                                                            I
26.00 TO  28.00    2 I**                                                                                            I
28.00 TO  30.00    6 I******                                                                                        I
30.00 TO  32.00   10 I**********                                                                                    I
32.00 TO  34.00   15 I***************                                                                               I
34.00 TO  36.00   18 I******************                                                                            I
36.00 TO  38.00   26 I**************************                                                                    I
38.00 TO  40.00   28 I****************************                                                                  I
40.00 TO  42.00   28 I****************************                                                                  I
42.00 TO  44.00   29 I*****************************                                                                 I
44.00 TO  46.00   30 I******************************                                                                I
46.00 TO  48.00   30 I******************************                                                                I
48.00 TO  50.00   36 I************************************                                                          I
50.00 TO  52.00   30 I******************************                                                                I
52.00 TO  54.00   45 I*********************************************                                                 I
54.00 TO  56.00   20 I********************                                                                          I
56.00 TO  58.00   22 I**********************                                                                        I
58.00 TO  60.00   20 I********************                                                                          I
60.00 TO  62.00   18 I******************                                                                            I
62.00 TO  64.00   20 I********************                                                                          I
64.00 TO  66.00   20 I********************                                                                          I
66.00 TO  68.00    9 I*********                                                                                     I
68.00 TO  70.00    9 I*********                                                                                     I
70.00 TO  72.00    9 I*********                                                                                     I
72.00 TO  74.00    5 I*****                                                                                         I
74.00 TO  76.00    2 I**                                                                                            I
76.00 TO  78.00    4 I****                                                                                          I
78.00 TO  80.00    2 I**                                                                                            I
80.00 TO  82.00    0 I                                                                                              I
82.00 TO  84.00    0 I                                                                                              I
84.00 TO  86.00    1 I*                                                                                             I
86.00 TO  88.00    0 I                                                                                              I
88.00 TO  90.00    1 I*                                                                                             I
90.00 TO  92.00    1 I*                                                                                             I
```

Figure 13 (Cont.)
Histogram Output

Figure 13 (Cont.)
Histogram Output

```
          COAST FUEL CONSUMPTION HISTOGRAM

NO OF SAMPLES=  499  MIN= 11.89  MAX=  30.97
   RANGE        NUMBER 0    5    10   15   20   25   30   35   40   45   50   55   60   65   70   75   80   85   90   95
                       I....I....I....I....I....I....I....I....I....I....I....I....I....I....I....I....I....I....I....I
 11.00 TO  11.50     0 I
 11.50 TO  12.00     1 I*
 12.00 TO  12.50     0 I
 12.50 TO  13.00     2 I**
 13.00 TO  13.50     3 I***
 13.50 TO  14.00     7 I*******
 14.00 TO  14.50     5 I*****
 14.50 TO  15.00    10 I**********
 15.00 TO  15.50    13 I*************
 15.50 TO  16.00    14 I**************
 16.00 TO  16.50    14 I**************
 16.50 TO  17.00    21 I*********************
 17.00 TO  17.50    22 I**********************
 17.50 TO  18.00    34 I**********************************
 18.00 TO  18.50    39 I***************************************
 18.50 TO  19.00    36 I************************************
 19.00 TO  19.50    29 I*****************************
 19.50 TO  20.00    31 I*******************************
 20.00 TO  20.50    28 I****************************
 20.50 TO  21.00    37 I*************************************
 21.00 TO  21.50    25 I*************************
 21.50 TO  22.00    28 I****************************
 22.00 TO  22.50    23 I***********************
 22.50 TO  23.00    11 I***********
 23.00 TO  23.50    12 I************
 23.50 TO  24.00    13 I*************
 24.00 TO  24.50     6 I******
 24.50 TO  25.00    13 I*************
 25.00 TO  25.50     4 I****
 25.50 TO  26.00     7 I*******
 26.00 TO  26.50     1 I*
 26.50 TO  27.00     5 I*****
 27.00 TO  27.50     0 I
 27.50 TO  28.00     0 I
 28.00 TO  28.50     1 I*
 28.50 TO  29.00     2 I**
 29.00 TO  29.50     0 I
 29.50 TO  30.00     0 I
 30.00 TO  30.50     0 I
 30.50 TO  31.00     2 I**
 31.00 TO  31.50     1 I*
```

```
          TOTAL FUEL CONSUMPTION HISTOGRAM

NO OF SAMPLES=  499  MIN= 39.52  MAX= 113.31
   RANGE        NUMBER 0    5    10   15   20   25   30   35   40   45   50   55   60   65   70   75   80   85   90   95
                       I....I....I....I....I....I....I....I....I....I....I....I....I....I....I....I....I....I....I....I
 36.00 TO  38.00     0 I
 38.00 TO  40.00     1 I*
 40.00 TO  42.00     0 I
 42.00 TO  44.00     2 I**
 44.00 TO  46.00     1 I*
 46.00 TO  48.00     3 I***
 48.00 TO  50.00     5 I*****
 50.00 TO  52.00     9 I*********
 52.00 TO  54.00    16 I****************
 54.00 TO  56.00    15 I***************
 56.00 TO  58.00    11 I***********
 58.00 TO  60.00    31 I*******************************
 60.00 TO  62.00    30 I******************************
 62.00 TO  64.00    28 I****************************
 64.00 TO  66.00    39 I***************************************
 66.00 TO  68.00    20 I********************
 68.00 TO  70.00    29 I*****************************
 70.00 TO  72.00    40 I****************************************
 72.00 TO  74.00    37 I*************************************
 74.00 TO  76.00    23 I***********************
 76.00 TO  78.00    26 I**************************
 78.00 TO  80.00    18 I******************
 80.00 TO  82.00    17 I*****************
 82.00 TO  84.00    22 I**********************
 84.00 TO  86.00    18 I******************
 86.00 TO  88.00    13 I*************
 88.00 TO  90.00    13 I*************
 90.00 TO  92.00    10 I**********
 92.00 TO  94.00     5 I*****
 94.00 TO  96.00     3 I***
 96.00 TO  98.00     5 I*****
 98.00 TO 100.00     2 I**
100.00 TO 102.00     2 I**
102.00 TO 104.00     2 I**
104.00 TO 106.00     0 I
106.00 TO 108.00     1 I*
108.00 TO 110.00     1 I*
110.00 TO 112.00     0 I
112 00 TO 114.00     1 I*
114.00 TO 116.00     1 I*
```

Figure 13 (Concluded)
Histrogram Output

APPENDIX A

FORTRAN Program Listing

A complete listing of the FORTRAN Source Program is presented in the following pages. It starts with the MAIN routine and is followed by the seventeen (17) subroutines arranged in alphabetical order. There are a total of 947 cards in the MAIN routine. The total program including the subroutines contains 1,626 cards.

If the routine is used on a non-CDC computer the pseudo random number generation will change. In this case the calls to RANSET (line 29) and RANGET (lines 668, 743, and 829) should be deleted. Subroutine RNDX has an alternate pseudo random number generator coding which is listed as comment cards.

```
*DECK MAIN
      PROGRAM MAIN(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
C
C     SCOUT UPPER STAGE STATISTICAL FUEL CONSUMPTION ROUTINE
C     COMPUTES THE STATISTICAL DISTRIBUTION OF CONTROL FUEL CONSUMPTION
C     FOR AN ON-OFF REACTION JET ATTITUDE CONTROL SYSTEM BY THE MONTE
C     CARLO TECHNIQUE. THE EFFECT OF BOOSTER INDUCED DISTURBANCES AND
C     AERODYNAMIC DISTURBANCES ARE CONSIDERED IN ADDITION TO THE SELF
C     EXCITED LIMIT CYCLE MOTION.
      DIMENSION IO(9), A(16), TABL1(9), B(30), C(30), D(18), BT(15),
     1    PC(8), YC(8), RC(7), PDC(10), WBOOST(1000), TCOAST(1000),
     2    WCOAS(1000),TRET(1000),WTOT(1000),FWB(20),FWC(20),FWT(20),
     3    TBL1(90),TBL2(90),TBL3(90),TBL4(90),TBL5(90),TBL6(90),
     4    TBL7(90),TBL8(90),TBL9(90),TBL10(90),TBL11(90),
     5    TA1(50),TCX(50),VXX(50),GAP(50),ZPX(50),PSX(50),HX(50),
     6    VELX(50),X1KA(50),X1KB(50),VWMX(50),VWSX(50),THX(50),TOW(50),
     7WGHT(50),XINER(50),CNASQ(50)
      COMMON K, RXD(30)
      COMMON/DOUT/NQT,TBL1,NVT,TBL5,NGT,TBL6,NHT,TBL11,TBO,NTC,TBL4
      COMMON/DDI/TBL2,TBL3,NTHT,NWT,CDS,M2,M3,WBO
      DATA NUMCHI/11/
C     READ RUN NO.,NUMBER OF SAMPLES, AND RUN OPTIONS
   10 READ( 5,1330) NRUN,IT,(IO(I),I=1,9)
      IF (EOF(5).NE.0) STOP
C     READ TWO CARDS OF TITLE INFORMATION FOR OUTPUT ONLY
      READ( 5,1350)
C     READ INITIAL SEQUENCE INTEGER FOR RANF PSEUDO RANDOM NUMBER
      READ( 5,1320) K
      CALL RANSET (K)
      NPAGE=1
      NLINE=0
      CALL PAGEHD (NRUN,NPAGE,NLINE)
      WRITE( 6,1350)
      NLINE=NLINE+2
```

```
C     READ IN XCG AND MOMENT OF INERTIA TABLE
      READ( 5,1440) (TABL1(I),I=1,9)
C     READ IN SINGLE VALUED CONSTANTS
      READ( 5,1450) (A(I),I=1,16),CNAS,XCP,GAMEI,ZEI,QFRAC
      TBO=A(14)
      WBO=A(15)
      GAMEI=GAMEI/57.3
      ZEI=ZEI/57.3
C     READ IN MEAN AND STANDARD DEVIATIONS OF CONTROL MOTOR OVERSHOOT
C     RATIO,TIME TO PEAK THRUST, ADDED TURN-OFF TIME DELAY DUE TO
C     STRUCTURAL FLEXIBILITY
      READ( 5,1460) ORM,ORS,TPM,TPS,T2FM,T2FS
C     READ IN MEAN AND STANDARD DEVIATIONS OF BOOST AND CONTROL SYSTEM
      READ( 5,1460) (B(I),I=1,30)
      READ( 5,1460) (C(I),I=1,30)
      IF (IO(2)-3 .LT. 0 ) GO TO 20
C     SEPARATE COAST CONTROL SYSTEM OPTION IO(2)=3
C     READ IN TORQUEING RATE CHANGES AND RETRO PARAMETERS
      READ( 5,1450) PTRC,YTRC,TRETRO,RETRSI
C     READ IN COAST CONTROL SYSTEM VARIABLES, MEAN AND SIGMA
      READ( 5,1460) (D(I),I=1,18)
C     READ IN TABLES
   20 M2=1
      M3=1
C     TEST FOR INPUT OPTION TO CALCULATE OR READ IN Q,VEL,GAMMA,ALTITUDE
      IF (IO(8).EQ.0) GO TO 30
C     READ IN INITIAL Q,V,GAMMA AND DRAG COEFFICIENT CDS FOR CALCULATION
      READ( 5,990) QO,VO,GAMO,CDS
      READ( 5,1470) NTHT,(TBL2(I),I=1,NTHT)
      READ( 5,1470) NWT,(TBL3(I),I=1,NWT)
      READ( 5,1470) NTC,(TBL4(I),I=1,NTC)
      READ( 5,1470) NAZT,(TBL7(I),I=1,NAZT)
      READ( 5,1470) NSYT,(TBL8(I),I=1,NSYT)
      READ( 5,1470) NVMH,(TBL9(I),I=1,NVMH)
```

```
      READ( 5,1470) NVSH,(TBL10(I),I=1,NVSH)
C     CALCULATE Q,VELOCITY,GAMMA,AND ALTITUDE TABLES
      CALL TABGEN (QO,VO,GAMO)
      GO TO 40
C     IO(8)=0  READ IN ALL TRAJECTORY TABLES
   30 READ( 5,1470) NQT,(TBL1(I),I=1,NQT)
      READ( 5,1470) NTHT,(TBL2(I),I=1,NTHT)
      READ( 5,1470) NWT,(TBL3(I),I=1,NWT)
      READ( 5,1470) NTC,(TBL4(I),I=1,NTC)
      READ( 5,1470) NVT,(TBL5(I),I=1,NVT)
      READ( 5,1470) NGT,(TBL6(I),I=1,NGT)
      READ( 5,1470) NAZT,(TBL7(I),I=1,NAZT)
      READ( 5,1470) NSYT,(TBL8(I),I=1,NSYT)
      READ( 5,1470) NVMH,(TBL9(I),I=1,NVMH)
      READ( 5,1470) NVSH,(TBL10(I),I=1,NVSH)
      READ( 5,1470) NHT,(TBL11(I),I=1,NHT)
C     COMPUTE CONSTANTS FOR SECOND ORDER CURVE FITTING MASS PROPERTIES
   40 QR1=TABL1(7)/TABL1(4)
      QR2=TABL1(7)*(TABL1(7)-TABL1(4))
      SL2IY=(TABL1(8)-TABL1(2)+QR1*(TABL1(2)-TABL1(5)))/QR2
      SL1IY=(-TABL1(2)+TABL1(5)-SL2IY*TABL1(4)*TABL1(4))/TABL1(4)
      SL2CG=(TABL1(9)-TABL1(3)+QR1*(TABL1(3)-TABL1(6)))/QR2
      SL1CG=(-TABL1(3)+TABL1(6)-SL2CG*TABL1(4)*TABL1(4))/TABL1(4)
      NTB=IO(5)
      NTT=IO(6)
      MER1=0
      MRER1=0
      MERC=0
      NPK1=0
      NPK2=0
      NPK3=0
      NPK4=0
      SWB=0.
      STC=0.
```

```
      SWC=0.
      STR=0.
      SWT=0.
      ANTPW=IO(5)
      ANTPT=IO(6)
      TWEB=A(13)
      WTC=TBL3(2)
      DELT1=TWEB/ANTPW
      DELT2=(TBO-TWEB)/ANTPT
      PBFCT=0.0
      PCFCT=0.0
      YCFCT=0.0
      YBFCT=0.0
C     SET TABLE LOOKUP INDICES FOR INITIAL VALUE
      M1=1
      M2=1
      M3=1
      M4=1
      M5=1
      M6=1
      M7=1
      M8=1
      M9=1
      M10=1
      M11=1
      NTOT=NTB+NTT
      DELTA=DELT1
C
C     CALCULATE AND STORE THRUST MISALIGNMENT AND AERO COEFFICIENTS
C     AT TIME POINTS DURING BOOST PHASE
      TA=0.
      DO 50 J=1,NTOT
      IF(J.GT.NTB) DELTA=DELT2
      TA=TA+0.5*DELTA
```

```
      TA1(J)=TA
      CALL TBLU (NQT,Q,TA,TBL1,M1)
      CALL TBLU (NTHT,T,TA,TBL2,M2)
      CALL TBLU (NWT,WR,TA,TBL3,M3)
      CALL TBLU (NTC,TC,TA,TBL4,M4)
      CALL TBLU (NVT,V,TA,TBL5,M5)
      CALL TBLU (NGT,GAMP,TA,TBL6,M6)
      CALL TBLU (NAZT,ZP,TA,TBL7,M7)
      CALL TBLU (NSYT,BETPR,TA,TBL8,M8)
      CALL TBLU (NHT,H,TA,TBL11,M11)
      CALL TBLU (NVMH,VWM,H,TBL9,M9)
      CALL TBLU (NVSH,VWS,H,TBL10,M10)
      TCX(J)=TC/57.3
      VXX(J)=V
      GAP(J)=GAMP/57.3
      ZPX(J)=ZP/57.3
      PSX(J)=BETPR/57.3
      VWMX(J)=VWM
      VWSX(J)=VWS
      HX(J)=H
      PERCA=(WTC-WR)/WTC
      WT2=WBO+WR
      ACC=T*32.173/WT2
      VELX(J)=ACC*DELTA*C(11)/57.3
C     CALCULATE MOMENT OF INERTIA AND XCG AVERAGE DURING WEB BURN
      ERTIA=(TABL1(2)+SL1IY*PERCA+SL2IY*PERCA*PERCA)
      CGA=(TABL1(3)+SL1CG*PERCA+SL2CG*PERCA*PERCA)
      XERT=12.*ERTIA
      THX(J)=((A(4)-CGA)*A(8)+A(5)*A(9))/XERT
      X1KA(J)=CNAS*Q*(CGA-XCP)/XERT
      X1KB(J)=(A(6)-CGA)*T/XERT
      XINER(J)=ERTIA
      TOW(J)=T/WT2
      WGHT(J)=WT2
```

```
      CNASQ(J)=CNAS*Q
   50 CONTINUE
C
C     BEGIN THE MONTE CARLO RUNS
C
      DO 750 ITER=1,IT
C    CALCULATE AND TEST CONTROL MOTOR THRUST OVERSHOOT FACTORS
      IF (ORM-1.0 .LE. 0 ) GO TO 140
      CALL RNDX (8)
      ORPB=ORM+RXD(1)*ORS
      ORYB=ORM+RXD(2)*ORS
      ORPC=ORM+RXD(3)*ORS
      ORYC=ORM+RXD(4)*ORS
      TPPB=TPM+RXD(5)*TPS
      TPYB=TPM+RXD(6)*TPS
      TPPC=TPM+RXD(7)*TPS
      TPYC=TPM+RXD(8)*TPS
      IF (ORPB-1. .LE. 0 ) GO TO 70
      CALL OVRF (TPPB,ORPB,PBFCT)
      GO TO 80
   70 PBFCT=0.0
   80 IF (ORPC-1.0 .LE. 0 ) GO TO 90
      CALL OVRF (TPPC,ORPC,PCFCT)
      GO TO 100
   90 PCFCT=0.0
  100 IF (ORYB-1.0 .LE. 0 ) GO TO 110
      CALL OVRF (TPYB,ORYB,YBFCT)
      GO TO 120
  110 YBFCT=0.0
  120 IF (ORYC-1.0 .LE. 0 ) GO TO 130
      CALL OVRF (TPYC,ORYC,YCFCT)
      GO TO 140
  130 YCFCT=0.0
  140 CALL RNDX (1)
```

```
C     CALCULATE ADDITIONAL CONTROL MOTOR TURN-OFF DELAY DUE TO
C     STRUCTURAL FLEXIBILITY
      T2FLX=T2FM+RXD(1)*T2FS
C     COMPUTE BOOST PHASE INITIAL CONDITIONS, ET, DISTURBANCES
      CALL RNDX (16)
      DO 150 J=1,12
  150 BT(J)=B(2*J-1)+RXD(J)*B(2*J)
      BT(13)=B(25)*RXD(13)+1.
      BT(14)=B(26)*RXD(14)+1.
      SUP=B(27)+RXD(15)*B(28)
      SUY=B(29)+RXD(16)*B(30)
C     CALCULATE WIND DIRECTION
      DW=BT(12)/57.3
      BT(3)=B(5)+B(6)*(RXD(1)*A(2)+RXD(3)*SQRT((A(1)-1.)*(1.-A(2)*A(2))/
     1(A(1)-2.)))
      BT(4)=B(7)+B(8)*(RXD(2)*A(3)+RXD(4)*SQRT((A(1)-1.)*(1.-A(3)*A(3))/
     1(A(1)-2.)))
      CALL RNDX (1)
      QRD=1.+RXD(1)*QFRAC
C     SELECT CONTROL SYSTEM RANDOM VARIABLES
      CALL RNDX (16)
      DO 160 J=1,8
      PC(J)=C(2*J-1)+RXD(J)*C(2*J)
  160 YC(J)=C(2*J-1)+RXD(J+8)*C(2*J)
      CALL RNDX (7)
      DO 170 J=1,7
  170 RC(J)=C(2*J+15)+RXD(J)*C(2*J+16)
C     TEST FOR STAGE OPTION   2-NO COAST CONTROL  3-COAST CONTROL
      IF (IO(2)-3 .LT. 0 ) GO TO 190
C     CALCULATE RANDOM CONTROL SYSTEM CHARACTERISTICS FOR COAST WITH
C     SEPARATE COAST SYSTEM USING YAW-ROLL MIXING
      CALL RNDX (10)
      DO 180 J=1,4
      PDC(J)=D(2*J-1)+RXD(J)*D(2*J)
```

```
  180 PDC(J+4)=D(2*J+7)+RXD(J+4)*D(2*J+8)
      PDC(9)=D(1)+RXD(9)*D(2)
      PDC(10)=D(17)+RXD(10)*D(18)
      IF (IO(7)-1 .LT. 0 ) GO TO 190
C     COMPUTE COAST CONTROL VARIABLES WITHOUT YAW-ROLL MIXING
      CALL RNDX (3)
      YCF1=D(3)+RXD(1)*D(4)
      YCT1=D(5)+RXD(2)*D(6)
      YCT2=D(7)+RXD(3)*D(8)
C     COMPUTE ROLL TORQUES IMPULSE, CONTROL MOTOR TIME DELAYS,CONTROL
C     ACCELERATIONS AT IGNITION
  190 RTI=ABS(BT(10))*12./A(7)
      T1P=PC(1)+PC(2)+PC(3)
      T2P=PC(1)+PC(2)+PC(4)
      T1Y=YC(1)+YC(2)+YC(3)
      T2Y=YC(1)+YC(2)+YC(4)
      THEDDA=PC(8)*((A(4)-TABL1(3)*BT(14))*A(8)+A(9)*A(5))/(12.*TABL1(2)
     1*BT(13))
      PSDDA=THEDDA*YC(8)/PC(8)
C     COMPUTE CAPTURE MANUEVER IMPULSE
      CAPIMP=PC(8)*(2.*T2P+ABS((BT(6)+2.*(BT(7)-PC(6))/PC(5))/(57.3*THED
     1DA)))+YC(8)*(2.*T2Y+ABS((BT(8)+2.*(BT(9)-YC(6))/YC(5))/(57.3*PSDDA
     2)))
      BIMP=0.
      THETP=0.0
      THETY=0.0
      CALL RNDX (3)
      VEL1=GAMEI*TBL5(2)*RXD(1)
      VEL2=ZEI*TBL5(2)*RXD(2)
      WINDEX=RXD(3)
      NER1=0
      NRR1=0
      NERC=0
C
```

```
C     CALCULATE IMPULSE IN PITCH AND YAW DURING BOOST PHASE
C
      DELTA=DELT1
      DO 300 J=1,NTOT
      IF(J.GT.NTB) DELTA=DELT2
      TA=TA1(J)
      H=HX(J)
      TC=TCX(J)
      V=VXX(J)
      GAMP=GAP(J)
      ZP=ZPX(J)
      BETPR=PSX(J)
      CTHX=THX(J)/BT(13)
      VW=VWMX(J)+WINDEX*VWSX(J)
      SGAMP=SIN(GAMP)
      CGAMP=COS(GAMP)
      VWCSDZ=VW*COS(DW-ZP)
      XNUM1=VWCSDZ*SGAMP
      XNUM2=VW*SIN(DW-ZP)
      XDEN1=V+VWCSDZ*CGAMP
      QWDFAC=QRD*(XDEN1*2./V+(VW/V)**2-1.)
      XKA=QWDFAC*X1KA(J)/BT(13)
      XKB=X1KB(J)/BT(13)
C     COMPUTE THRUST MISALIGNMENT
      ETPA=(BT(1)+BT(3)*TA)/57.3
      ETYA=(BT(2)+BT(4)*TA)/57.3
      THEDDA=PC(8)*CTHX
      PSDDA=THEDDA*YC(8)/PC(8)
C     COMPUTE ANGLES OF ATTACK IN PITCH AND YAW
      GAME1=VEL1/V
      ZE1=VEL2/V
C     CALCULATE ALPHA DUE TO WINDS
      ALPHW=(XNUM1/XDEN1)
C     CALCULATE BETA DUE TO WINDS
```

```
      BETAW=(XNUM2/XDEN1)
      ALPHP=TC-GAMP-GAME1+ALPHW
      BETAP=BETPR+BETAW+ZE1
C     CALCULATE PITCH AND YAW ACCEL DUE TO THRUST MISALIGNMENT , AERO
C     AND CG OFF-SET
      TOWI=TOW(J)/(XINER(J)*BT(13))
      THETP=XKA*ALPHP+XKB*ETPA+SUP*TOWI
      THETY=-XKA*BETAP+XKB*ETYA+SUY*TOWI
C     PICK DEADBAND SIDE AND ADD DEADBAND TO ANGLE OF ATTACK
      IF (THETP) 210,220,200
C     COMPUTE CROSS TRACK VELOCITY ERROR UPDATE
  200 VEL1=VEL1+VELX(J)
      GAME=VEL1/V
      DALP=C(11)/57.3-(GAME-GAME1)/2.
      DADBP=DALP*XKA
      THETP=THETP+DADBP
      GO TO 220
  210 VEL1=VEL1-VELX(J)
      GAME=VEL1/V
      DALP=-C(11)/57.3-(GAME-GAME1)/2.
      DADBP=DALP*XKA
      THETP=THETP+DADBP
  220 IF (THETY) 240,250,230
  230 VEL2=VEL2+VELX(J)
      ZE=VEL2/V
      DBET=-C(11)/57.3+(ZE-ZE1)/2.
      DADBY=-DBET*XKA
      THETY=THETY+DADBY
      GO TO 250
  240 VEL2=VEL2-VELX(J)
      ZE=VEL2/V
      DBET=+C(11)/57.3+(ZE-ZE1)/2.
      DADBY=-DBET*XKA
      THETY=THETY+DADBY
```

```
C     CALL SUBROUTINE FOR COMPUTING MINIMUM DISTURBING ACCELERATION FOR
C     ONE SIDED LIMIT CYCLE
  250 CALL THEMIN (THEDDA,PC(5),PC(6),PC(7),T1P,T2P,THMIN)
      IF (ABS(THETP)-THMIN .GE. 0 ) GO TO 260
      CALL CYCLE (THEDDA,PC(5),PC(6),PC(7),T1P,T2P,DCP,AP,NERR1,PBFCT)
      GO TO 270
C     COMPUTE DUTY CYCLE AND INCREMENTAL IMPULSE
  260 DCP=ABS(THETP/THEDDA)
  270 DPI=DCP*PC(8)*DELTA
      CALL THEMIN (PSDDA,YC(5),YC(6),YC(7),T1Y,T2Y,THMIN)
      IF (ABS(THETY)-THMIN .GE. 0 ) GO TO 280
      CALL CYCLE (PSDDA,YC(5),YC(6),YC(7),T1Y,T2Y,DCY,AY,NERR1,YBFCT)
      GO TO 290
  280 DCY=ABS(THETY/PSDDA)
  290 DYI=DCY*YC(8)*DELTA
C     COMPUTE ROLL IMPULSE DUE TO CG OFFSET
      THXW=THX(J)*WGHT(J)
      TWLTLP=X1KB(J)/THXW
      TWWLP=TOW(J)/(THXW*XINER(J))
      CNAWL=QWDFAC*X1KA(J)/THXW
      ALP=DALP+ALPHP
      BET=DBET+BETAP
      RM=TOW(J)*(SUP*ETYA-SUY*ETPA)+QWDFAC*CNASQ(J)*(SUY*ALP+
     1 SUP*BET)/WGHT(J)+SUY*(TWLTLP*ETPA+TWWLP*SUP+
     2 CNAWL*ALP)-SUP*(TWLTLP*ETYA+TWWLP*SUY-CNAWL*BET)
C     COMPUTE INCREMENTAL ROLL IMPULSE
      RIMP=12.*ABS(RM)*DELTA/A(7)
  300 BIMP=BIMP+ABS(DPI)+ABS(DYI)+RIMP
C     COMPUTE TOTAL BOOST IMPULSE AND FUEL CONSUMPTION
      BIMP=(BIMP+CAPIMP)*(1.+(A(5)*A(8)*ABS(BT(11)))/(57.3*A(7)))+RTI
      WBOOST(ITER)=BIMP/BT(5)
      SWB=SWB+WBOOST(ITER)
C     COMPUTE LIMIT CYCLE FUEL CONSUMPTION DURING COAST WITH FILTER
C     IN USING BOOST CONTROL SYSTEM
```

```
      THEDDA=PC(8)*((A(4)-BT(14)*TABL1(9))*A(8)+A(5)*A(9))/(12.*TABL1(8)
     1*BT(13))
      PSDDA=THEDDA*YC(8)/PC(8)
      PHIDD=RC(7)*A(7)/(6.*A(16))
      CALL CYCLE (THEDDA,PC(5),PC(6),PC(7),T1P,T2P,DCP,AP,NERR1,PBFCT)
      NER1=NER1+NERR1
      CALL CYCLE (PSDDA,YC(5),YC(6),YC(7),T1Y,T2Y,DCY,AY,NERR1,YBFCT)
      NER1=NER1+NERR1
      T1R=RC(1)+RC(2)
      T2R=RC(1)+RC(3)
      CALL CYCLE (PHIDD,RC(4),RC(5),RC(6),T1R,T2R,DCR,AR,NERR1,0.)
      NRR1=NRR1+NERR1
C     COMPUTE CONTROL FUEL FLOW RATE LIMIT CYCLE WITH BOOST CONTROLS
      WDFILT=(DCP*PC(8)+DCY*YC(8)+DCR*RC(7)*2.)/BT(5)
      TTO=TBO-TWEB
C     TEST FOR COAST FILTER OPTION 1-COAST FILTER OUT 2-COAST FILTER IN
      IF (IO(4)-2 .GE. 0 ) GO TO 420
C     COMPUTE FUEL WITH FILTER IN COAST FOR OPTION WITH FILTER SWITCHED
C     OUT DURING COAST
      DELT=A(10)-TBO
      WFILT=WDFILT*DELT
      GO TO 530
C     TEST FOR STAGE OPTION   2-NO COAST CONTROL  3-COAST CONTROL
  420 IF (IO(2)-3 .GE. 0 ) GO TO 490
C     BOOST AND COAST CONTROL SYSTEM IS THE SAME
C     TEST FOR COAST OPTION  1-COAST TIME  2-COAST FUEL
      IF (IO(3)-2 .GE. 0 ) GO TO 460
C     STAGE 2 COAST TIME - FILTER IN
      TCOAST(ITER)=(A(12)-WBOOST(ITER))/WDFILT
      STC=STC+TCOAST(ITER)
C     TEST FOR PRINT OPTION  1-INDIVIDUAL SAMPLE DATA, 2-ONLY STATISTICS
      IF (IO(1)-2 .GE. 0 ) GO TO 600
  430 IF (NPK1 .NE. 0 ) GO TO 450
  440 NPAGE=NPAGE+1
```

```
      CALL PAGEHD (NRUN,NPAGE,NLINE)
      WRITE( 6,980)
      WRITE( 6,1010)
      NLINE=NLINE+6
      NPK1=1
  450 IF (NLINE+3-62 .GT. 0 ) GO TO 440
      WRITE( 6,1000) ITER,CAPIMP,RTI,BIMP,TWEB,TTO,WBOOST(ITER),BT(5)
      WRITE( 6,1020) TCOAST(ITER),WDFILT,NER1,NRR1
      NLINE=NLINE+3
      GO TO 600
C     STAGE 2 COAST FUEL - FILTER IN
  460 WCOAS(ITER)=A(11)*WDFILT
      SWC=SWC+WCOAS(ITER)
      WTOT(ITER)=WBOOST(ITER)+WCOAS(ITER)
      SWT=SWT+WTOT(ITER)
C     TEST PRINT OPTION   1-INDIVIDUAL SAMPLE DATA, 2-ONLY STATISTICAL
      IF (IO(1)-2 .GE. 0 ) GO TO 600
      IF (NPK1 .NE. 0 ) GO TO 480
  470 NPAGE=NPAGE+1
      CALL PAGEHD (NRUN,NPAGE,NLINE)
      WRITE( 6,980)
      WRITE( 6,1030)
      NLINE=NLINE+6
      NPK1=1
  480 IF (NLINE+3-62 .GT. 0 ) GO TO 470
      WRITE( 6,1000) ITER,CAPIMP,RTI,BIMP,TWEB,TTO,WBOOST(ITER),BT(5)
      WRITE( 6,1040) WCOAS(ITER),WDFILT,NER1,NRR1,WTOT(ITER)
      NLINE=NLINE+3
      GO TO 600
C     SEPARATE COAST CONTROL IO(2)=3
C     TEST FOR COAST OPTION  1-COAST TIME  2-COAST FUEL AND RETRO TIME
  490 IF (IO(3)-2 .GE. 0 ) GO TO 500
C     COMPUTE STAGE 3  COAST TIME - FILTER IN
      TCOAST(ITER)=(A(12)-WBOOST(ITER)-2.*(PC(8)+YC(8)+RC(7))*TRETRO/RET
```

```
     1RSI)/WDFILT
      STC=STC+TCOAST(ITER)
C     TEST PRINT OPTION  1-INDIVIDUAL SAMPLE DATA, 2-ONLY STATISTICAL
      IF(IO(1)) 430,600,600
C     COMPUTE STAGE 3 COAST FUEL, RETRO TIME AND TOTAL FUEL FILTER IN
  500 WCOAS(ITER)=A(11)*WDFILT
      WRETRO=A(12)-WBOOST(ITER)-WCOAS(ITER)
      TRET(ITER)=WRETRO*RETRSI/(2.*(PC(8)+YC(8)+RC(7)))
      SWC=SWC+WCOAS(ITER)
      STR=STR+TRET(ITER)
      WTOT(ITER)=A(12)-WRETRO*(1.-TRETRO/TRET(ITER))
      SWT=SWT+WTOT(ITER)
C     TEST PRINT OPTION  1-INDIVIDUAL SAMPLE DATA 2-ONLY STATISTICAL
      IF (IO(1)-2 .GE. 0 ) GO TO 600
      IF (NPK1 .NE. 0 ) GO TO 520
  510 NPAGE=NPAGE+1
      CALL PAGEHD (NRUN,NPAGE,NLINE)
      WRITE( 6,980)
      WRITE( 6,1030)
      NLINE=NLINE+6
      NPK1=1
  520 IF (NLINE+3-62 .GT. 0 ) GO TO 510
      WRITE( 6,1000) ITER,CAPIMP,RTI,BIMP,TWEB,TTO,WBOOST(ITER),BT(5)
      WRITE( 6,1040) WCOAS(ITER),WDFILT,NER1,NRR1,WTOT(ITER)
      NLINE=NLINE+3
      GO TO 600
C     FILTER OUT COAST OPTION
C     TEST FOR STAGE OPTION  2-NO COAST CONTROL  3-COAST CONTROL
  530 IF (IO(2)-3 .GE. 0 ) GO TO 550
C     WITH BOOST CONTROL, FILTER OUT IN COAST
      T1P=PC(2)+PC(3)
      T2P=PC(2)+PC(4)+T2FLX
      T1Y=YC(2)+YC(3)
      T2Y=YC(2)+YC(4)+T2FLX
```

```
      CALL CYCLE (THEDDA,PC(5),PC(6),PC(7),T1P,T2P,DCP,AT,NERR1,PCFCT)
      NERC=NERC+NERR1
      CALL CYCLE (PSDDA,YC(5),YC(6),YC(7),T1Y,T2Y,DCY,AT,NERR1,YCFCT)
      NERC=NERC+NERR1
      WDCST=(DCR*RC(7)*2.+DCP*PC(8)+DCY*YC(8))/BT(5)
C     TEST FOR COAST OPTION  1-COAST TIME  2-COAST FUEL AND RETRO TIME
      IF (IO(3)-2 .GE. 0 ) GO TO 540
C     COMPUTE COAST TIME
      TCOAST(ITER)=DELT+(A(12)-WBOOST(ITER)-WFILT)/WDCST
      STC=STC+TCOAST(ITER)
      GO TO 600
C     COMPUTE COAST FUEL AND BOOST+COAST FUEL
C     COAST TIME IS ONLY PORTION WITH FILTER SWITCHED OUT; COAST FUEL
C     INCLUDES FILTER IN AND FILTER OUT COAST TIMES
  540 WCOAS(ITER)=A(11)*WDCST+WFILT
      SWC=SWC+WCOAS(ITER)
      WTOT(ITER)=WBOOST(ITER)+WCOAS(ITER)
      SWT=SWT+WTOT(ITER)
      GO TO 600
C     STAGE 3 OPTION
C     SEPARATE COAST CONTROL FILTER OUT IN COAST AND YAW-ROLL MIXING
C     2 ROLL MOTORS FOR YAW; 2 ROLL MOTORS FOR ROLL
  550 THEDDA=THEDDA*PDC(2)/PC(8)
      PSDDA=PSDDA*2.*PDC(6)/YC(8)
      PHIDD=PHIDD*PDC(6)/RC(7)
      T1P=PC(2)+PDC(3)
      T2P=PC(2)+PDC(4)+T2FLX
      T1Y=YC(2)+PDC(7)
      T2Y=YC(2)+PDC(8)+T2FLX
      T1R=RC(1)+PDC(7)
      T2R=RC(1)+PDC(8)
C     COMPUTE PITCH, YAW, ROLL TORQUEING AND DEADBAND REDUCTION FUEL
      PRTRW=(PDC(2)*(2.*T2P+ABS((PTRC+57.3*AP+2.*(PC(6)-PDC(1))/PC(5))/(
     157.3*THEDDA)))
```

```
      YRTRW=2.*PDC(6)*(2.*T2Y+ABS((YTRC+57.3*AY+2.*(YC(6)-PDC(9))/YC(5))
     1/(57.3*PSDDA)))
      RRTRW=2.*PDC(6)*(2.*T2R+ABS((57.3*AR+2.*(RC(5)-PDC(5))/RC(4))/(57.
     13*PHIDD)))
C     TEST COAST SYSTEM IO(7)= 0 YAW-ROLL MIXING,  =1 NO MIXING
      IF (IO(7)-1 .LT. 0 ) GO TO 560
C     NO YAW-ROLL MIXING, SEPARATE PITCH AND YAW MOTORS
      PSDDA=PSDDA*YCF1/(2.*PDC(6))
      T1Y=YC(2)+YCT1
      T2Y=YC(2)+YCT2+T2FLX
      YRTRW=YCF1*(2.*T2Y+ABS((YTRC+57.3*AY+2.*(YC(6)-PDC(9))/YC(5))/(57.
     13*PSDDA)))
C     COMPUTE FUEL REQUIRED FOR DEADBAND REDUCTION AND TORQUEING
  560 TRDRW=(PRTRW+YRTRW+RRTRW)/PDC(10)
      CALL CYCLE (THEDDA,PC(5),PDC(1),PC(7),T1P,T2P,DCP,AT,NERR1,PCFCT)
      NERC=NERC+NERR1
      CALL CYCLE (PSDDA,YC(5),PDC(9),YC(7),T1Y,T2Y,DCY,AT,NERR1,YCFCT)
      NERC=NERC+NERR1
      CALL CYCLE (PHIDD,RC(4),PDC(5),RC(6),T1R,T2R,DCR,AT,NERR1,0.0)
      NERC=NERC+NERR1
C     TEST FOR COAST CONTROL SYSTEM  0=YAW-ROLL MIXING, 1= NO MIXING
      IF (IO(7)-1 .GE. 0 ) GO TO 570
C     YAW-ROLL MIXING
      WDCST=(PDC(2)*DCP+2.*PDC(6)*(DCY+DCR))/PDC(10)
      GO TO 580
  570 WDCST=(PDC(2)*DCP+2.*PDC(6)*DCR+YCF1*DCY)/PDC(10)
C     TEST FOR COAST OPTION  1-COAST TIME  2-COAST FUEL AND RETRO TIME
  580 IF (IO(3)-2 .GE. 0 ) GO TO 590
C     COAST TIME OPTION
      TCOAST(ITER)=DELT+(A(12)-WBOOST(ITER)-WFILT-TRDRW-(PC(8)+YC(8)+RC(
     17))*2.*TRETRO/RETRSI)/WDCST
      STC=STC+TCOAST(ITER)
      GO TO 600
C     STAGE 3 COAST FUEL, RETRO TIME, TOTAL FUEL WITH INPUT RETRO TIME
```

```
  590 WCOAS(ITER)=A(11)*WDCST+WFILT
      SWC=SWC+WCOAS(ITER)
      WRETRO=A(12)-WBOOST(ITER)-TRDRW-WCOAS(ITER)
      TRET(ITER)=WRETRO*RETRSI/(2.*(PC(8)+YC(8)+RC(7)))
      STR=STR+TRET(ITER)
      WTOT(ITER)=A(12)-WRETRO*(1.-TRETRO/TRET(ITER))
      SWT=SWT+WTOT(ITER)
C     UPDATE COUNTER ON NUMBER OF DEADBAND OVERSHOOT CASES
  600 IF (NER1-1 .LT. 0 ) GO TO 610
      MER1=MER1+1
  610 IF (NRR1-1 .LT. 0 ) GO TO 620
      MRER1=MRER1+1
  620 IF (NERC-1 .LT. 0 ) GO TO 630
      MERC=MERC+1
C     TEST FOR COAST FILTER OPTION 1-COAST FILTER OUT 2-COAST FILTER IN
  630 IF (IO(4)-2 .GE. 0 ) GO TO 750
C     TEST PRINT OPTION 1-INDIVIDUAL SAMPLE RESULTS, 2-ONLY STATISTICAL
      IF (IO(1)-2 .GE. 0 ) GO TO 750
C     TEST FOR STAGE OPTION   2-BOOST CONTROL COAST  3-COAST CONTROL
      IF (IO(2)-3 .GE. 0 ) GO TO 690
C      TEST FOR COAST OPTION  1-COAST TIME  2-COAST FUEL AND RETRO TIME
      IF (IO(3)-2 .GE. 0 ) GO TO 660
      IF (NPK1 .NE. 0 ) GO TO 650
C     PRINT COAST TIME
  640 NPAGE=NPAGE+1
      CALL PAGEHD (NRUN,NPAGE,NLINE)
      WRITE( 6,980)
      WRITE( 6,1050)
      NLINE=NLINE+6
      NPK1=1
  650 IF (NLINE+3-62 .GT. 0 ) GO TO 640
      WRITE( 6,1000) ITER,CAPIMP,RTI,BIMP,TWEB,TTO,WBOOST(ITER),BT(5)
      WRITE( 6,1060) TCOAST(ITER),WDFILT,WDCST,NER1,NRR1
      NLINE=NLINE+3
```

```
      GO TO 750
C     PRINT COAST FUEL AND RETRO TIME
  660 IF (NPK1 .NE. 0 ) GO TO 680
  670 NPAGE=NPAGE+1
      CALL PAGEHD (NRUN,NPAGE,NLINE)
      WRITE( 6,980)
      WRITE( 6,1070)
      NLINE=NLINE+6
      NPK1=1
  680 IF (NLINE+3-62 .GT. 0 ) GO TO 670
      WRITE( 6,1000) ITER,CAPIMP,RTI,BIMP,TWEB,TTO,WBOOST(ITER),BT(5)
      WRITE( 6,1080) WCOAS(ITER),WDFILT,WDCST,NER1,NRR1,NERC,WTOT(ITER)
      NLINE=NLINE+3
      GO TO 750
C     TEST FOR COAST OPTION  1-COAST TIME  2-COAST FUEL AND RETRO TIME
  690 IF (IO(3)-2 .GE. 0 ) GO TO 720
C     PRINT COAST TIME
      IF (NPK1 .NE. 0 ) GO TO 710
  700 NPAGE=NPAGE+1
      CALL PAGEHD (NRUN,NPAGE,NLINE)
      WRITE( 6,980)
      WRITE( 6,1090)
      NLINE=NLINE+6
      NPK1=1
  710 IF (NLINE+3-62 .GT. 0 ) GO TO 700
      WRITE( 6,1000) ITER,CAPIMP,RTI,BIMP,TWEB,TTO,WBOOST(ITER),BT(5)
      WRITE( 6,1100) TCOAST(ITER),WDFILT,TRDRW,WDCST,NER1,NRR1,NERC
      NLINE=NLINE+3
      GO TO 750
C     PRINT COAST FUEL AND RETRO TIME
  720 IF (NPK1 .NE. 0 ) GO TO 740
  730 NPAGE=NPAGE+1
      CALL PAGEHD (NRUN,NPAGE,NLINE)
      WRITE( 6,980)
```

```
      WRITE( 6,1110)
      NLINE=NLINE+6
      NPK1=1
  740 IF (NLINE+3-62 .GT. 0 ) GO TO 730
      WRITE( 6,1000) ITER,CAPIMP,RTI,BIMP,TWEB,TTO,WBOOST(ITER),BT(5)
      WRITE( 6,1120) WCOAS(ITER),WDFILT,TRDRW,WDCST,TRET(ITER),NER1,NRR1
     1,NERC,WTOT(ITER)
      NLINE=NLINE+3
  750 CONTINUE
C
C     END OF INDIVIDUAL SAMPLE CALCULATION LOOP
C
C     BEGIN PART 2 STATISTICAL ANALYSIS
      AVI=IT
      VI=AVI+1.
      VIB=AVI-1.
      WBMEAN=SWB/AVI
C     TEST FOR COAST OPTION  1-COAST TIME  2-COAST FUEL AND RETRO TIME
      IF (IO(3)-2 .GE. 0 ) GO TO 790
C     COAST TIME OPTION
      TCMEAN=STC/AVI
C     CALL SUBROUTINE FOR REARRANGING ARRAYS
      CALL ASCEND (IT,WBOOST,0)
      CALL ASCEND (IT,TCOAST,1)
      SDXWB=0.
      SDXTC=0.
C     COMPUTE DISCRETE SAMPLE PROBABILITY LEVEL,SUM VALUES AND SQUARES
      DO 780 KAB=1,IT
      XKAB=KAB
      PROB=XKAB/VI
      DXWB=(WBMEAN-WBOOST(KAB))**2
      DXTC=(TCMEAN-TCOAST(KAB))**2
      SDXWB=SDXWB+DXWB
      SDXTC=SDXTC+DXTC
```

```
C     PRINT ELEMENTS OF REARRANGED ARRAY AS COMPUTED
      IF (NPK2 .NE. 0 ) GO TO 770
  760 NPAGE=NPAGE+1
      CALL PAGEHD (NRUN,NPAGE,NLINE)
      WRITE( 6,1130)
      NLINE=NLINE+4
      NPK2=1
  770 IF (NLINE+1-62 .GT. 0 ) GO TO 760
      WRITE( 6,1140) PROB,WBOOST(KAB),TCOAST(KAB)
      NLINE=NLINE+1
  780 CONTINUE
C     PRINT MEAN,SIGMA,LAST RANDOM SEQUENCE INTEGER,NO. OF DEADBAND OVER
C     SHOOT CASES
      SIGB=SQRT(SDXWB/VIB)
      SIGT=SQRT(SDXTC/VIB)
      NPAGE=NPAGE+1
      CALL PAGEHD (NRUN,NPAGE,NLINE)
      WRITE( 6,1150)
      WRITE( 6,1160) WBMEAN,TCMEAN
      WRITE( 6,1170) SIGB,SIGT
C     FIND LAST RANDOM SEQUENCE INTEGER,CDC RANF RANDOM NUMBER GENERATOR
      CALL RANGET (K)
      WRITE( 6,1180) K
      WRITE( 6,1190)
      WRITE( 6,1200) MER1
      WRITE( 6,1210) MRER1
      WRITE( 6,1220) MERC
      GO TO 10
C     OPTION FOR FUEL CONSUMPTION
  790 WCMEAN=SWC/AVI
      WTOTM=SWT/AVI
C     TEST FOR STAGE OPTION  2-COAST WITH CONTROL  3-COAST CONTROL
      IF (IO(2)-3 .LT. 0 ) GO TO 870
C     SEPARATE COAST CONTROL OPTION
```

```
      TRETM=STR/AVI
      CALL ASCEND (IT,WBOOST,0)
      CALL ASCEND (IT,WCOAS,0)
      CALL ASCEND (IT,WTOT,0)
      CALL ASCEND (IT,TRET,1)
      SDXWB=0.
      SDXFC=0.
      SDXWT=0.
      SDXRT=0.
C     CALCULATE PROBABILITIES OF FUEL CONSUMPTION AND RETRO TIME
      DO 820 KAB=1,IT
      XKAB=KAB
      PROB=XKAB/VI
      DXWB=(WBMEAN-WBOOST(KAB))**2
      DXFC=(WCMEAN-WCOAS(KAB))**2
      DXWT=(WTOTM-WTOT(KAB))**2
      DXRT=(TRETM-TRET(KAB))**2
      SDXWB=SDXWB+DXWB
      SDXFC=SDXFC+DXFC
      SDXWT=SDXWT+DXWT
      SDXRT=SDXRT+DXRT
C     PRINT ELEMENTS OF REARRANGED ARRAY AS COMPUTED
      IF (NPK3 .NE. 0 ) GO TO 810
  800 NPAGE=NPAGE+1
      CALL PAGEHD (NRUN,NPAGE,NLINE)
      WRITE( 6,1230)
      NLINE=NLINE+4
      NPK3=1
  810 IF (NLINE+1-62 .GT. 0 ) GO TO 800
      WRITE( 6,1240) PROB,WBOOST(KAB),WCOAS(KAB),TRET(KAB),WTOT(KAB)
      NLINE=NLINE+1
  820 CONTINUE
      SIGB=SQRT(SDXWB/VIB)
      SIGWC=SQRT(SDXFC/VIB)
```

```
      SIGWT=SQRT(SDXWT/VIB)
      SIGRT=SQRT(SDXRT/VIB)
      IF (IT-100 .LT. 0 ) GO TO 850
      ANI=0.995*VI
      NI=ANI
      ANIP=NI
      IF (.5-(ANI-ANIP) .GT. 0 ) GO TO 840
      NI=NI+1
  840 CONTINUE
C     COMPUTE UPPER 95% CONFIDENCE LEVEL ON 99.5% PROBABILITY LEVEL
      DEN=SQRT(1.-1.96*SQRT(2./(AVI-1.)))
      XK=1./DEN
      XWB95=WBMEAN+XK*(WBOOST(NI)-WBMEAN)
      XWC95=WCMEAN+XK*(WCOAS(NI)-WCMEAN)
      XWT95=WTOTM+XK*(WTOT(NI)-WTOTM)
      XRET95=TRETM+XK*(TRET(NI)-TRETM)
  850 NPAGE=NPAGE+1
      CALL PAGEHD (NRUN,NPAGE,NLINE)
      WRITE( 6,1340)
      WRITE( 6,1350)
      WRITE( 6,1340)
      WRITE( 6,1250)
      WRITE( 6,1260) WBMEAN,WCMEAN,TRETM,WTOTM
      WRITE( 6,1270) SIGB,SIGWC,SIGRT,SIGWT
      IF (IT-100 .LT. 0 ) GO TO 860
      WRITE( 6,1310) XWB95,XWC95,XRET95,XWT95
  860 CONTINUE
C     RETRIEVE LAST RANDOM SEQUENCE INTEGER
      CALL RANGET (K)
      WRITE( 6,1180) K
      WRITE( 6,1190)
      WRITE( 6,1200) MER1
      WRITE( 6,1210) MRER1
      WRITE( 6,1220) MERC
```

```
C     COMPUTE STATISTICS AND COMPARE WITH NORMAL,LOG-NORMAL,AND WEIBULL
C     STATISTICAL DISTRIBUTION FUNCTIONS
      CALL WBL (IT,WBOOST,NUMCHI,FWB)
      CALL WBL (IT,WCOAS,NUMCHI,FWC)
      CALL WBL (IT,WTOT,NUMCHI,FWT)
      WRITE( 6,1400)
      WRITE( 6,1410) ((FWB(J),FWC(J),FWT(J)),J=1,4),FWB(9),FWC(9),FWT(9)
     1,FWB(18),FWC(18),FWT(18)
      WRITE( 6,1420)
      WRITE( 6,1410) ((FWB(J),FWC(J),FWT(J)),J=5,8),FWB(10),FWC(10),FWT(
     110),FWB(19),FWC(19),FWT(19)
      WRITE( 6,1430) ((FWB(J),FWC(J),FWT(J)),J=11,17),FWB(20),FWC(20),FW
     1T(20)
C     TEST FOR HISTOGRAM OUTPUT OPTION  IO(9)=0 HISTOGRAMS, =1 NONE
      IF (IO(9).EQ.1) GO TO 10
C     CALCULATE AND PLOT HISTOGRAMS
      NDX=30
C     COMPUTE RANGE OF VARIABLES AND PLOT HISTOGRAM FOR RETRO TIME
      CALL RANGE (TRET,IT,GREAT,SMALL,DX,NDX,ERRTB)
      IF (ERRTB .GT. 0 ) GO TO 950
      WRITE( 6,1390)
      CALL HISTO (TRET,IT,GREAT,SMALL,DX)
      GO TO 950
C     STAGE 3- SEPARATE COAST CONTROL OPTION
  870 CALL ASCEND (IT,WBOOST,0)
      CALL ASCEND (IT,WCOAS,0)
      CALL ASCEND (IT,WTOT,0)
      SDXWB=0.
      SDXFC=0.
      SDXWT=0.
C     COMPUTE PROBABILITY DISTRIBUTION AND SUM OF SQUARES
      DO 900 KAB=1,IT
      XKAB=KAB
      PROB=XKAB/VI
```

```
      DXWB=(WBMEAN-WBOOST(KAB))**2
      DXFC=(WCMEAN-WCOAS(KAB))**2
      DXWT=(WTOTM-WTOT(KAB))**2
      SDXWB=SDXWB+DXWB
      SDXFC=SDXFC+DXFC
      SDXWT=SDXWT+DXWT
C     PRINT ELEMENTS OF REARRANGED ARRAY AS COMPUTED
      IF (NPK4 .NE. 0 ) GO TO 890
  880 NPAGE=NPAGE+1
      CALL PAGEHD (NRUN,NPAGE,NLINE)
      WRITE( 6,1280)
      NLINE=NLINE+4
      NPK4=1
  890 IF (NLINE+1-62 .GT. 0 ) GO TO 880
      WRITE( 6,1290) PROB,WBOOST(KAB),WCOAS(KAB),WTOT(KAB)
      NLINE=NLINE+1
  900 CONTINUE
C     COMPUTE STANDARD DEVIATION
      SIGB=SQRT(SDXWB/VIB)
      SIGWC=SQRT(SDXFC/VIB)
      SIGWT=SQRT(SDXWT/VIB)
      IF (IT-100 .LT. 0 ) GO TO 930
      ANI=0.995*VI
      NI=ANI
      ANIP=NI
      IF (.5-(ANI-ANIP) .GT. 0 ) GO TO 920
      NI=NI+1
  920 CONTINUE
C     COMPUTE UPPER 95% CONFIDENCE LEVEL, 99.5% PROBABILITY LEVEL
      DEN=SQRT(1.-1.96*SQRT(2./(AVI-1.)))
      XK=1./DEN
      XWB95=WBMEAN+XK*(WBOOST(NI)-WBMEAN)
      XWC95=WCMEAN+XK*(WCOAS(NI)-WCMEAN)
      XWT95=WTOTM+XK*(WTOT(NI)-WTOTM)
```

```
  930 NPAGE=NPAGE+1
      CALL PAGEHD (NRUN,NPAGE,NLINE)
      WRITE( 6,1340)
      WRITE( 6,1350)
      WRITE( 6,1340)
      WRITE( 6,1300)
      WRITE( 6,1260) WBMEAN,WCMEAN,WTOTM
      WRITE( 6,1270) SIGB,SIGWC,SIGWT
      IF (IT-100 .LT. 0 ) GO TO 940
      WRITE( 6,1310) XWB95,XWC95,XWT95
  940 CONTINUE
C     FIND LAST RANDOM SEQUENCE INTEGER
      CALL RANGET (K)
      WRITE( 6,1180) K
      WRITE( 6,1190)
      WRITE( 6,1200) MER1
      WRITE( 6,1210) MRER1
      WRITE( 6,1220) MERC
C     COMPUTE STATISTICAL PARAMETERS AND FIT TO NORMAL,LOG-NORMAL, AND
C     WEIBULL DISTRIBUTION FUNCTIONS
      CALL WBL (IT,WBOOST,NUMCHI,FWB)
      CALL WBL (IT,WCOAS,NUMCHI,FWC)
      CALL WBL (IT,WTOT,NUMCHI,FWT)
      WRITE( 6,1400)
      WRITE( 6,1410) ((FWB(J),FWC(J),FWT(J)),J=1,4),FWB(9),FWC(9),FWT(9)
     1,FWB(18),FWC(18),FWT(18)
      WRITE( 6,1420)
      WRITE( 6,1410) ((FWB(J),FWC(J),FWT(J)),J=5,8),FWB(10),FWC(10),FWT(
     110),FWB(19),FWC(19),FWT(19)
      WRITE( 6,1430) ((FWB(J),FWC(J),FWT(J)),J=11,17),FWB(20),FWC(20),FW
     1T(20)
C     TEST FOR HISTOGRAM OUTPUT  IO(9)=0 GIVES HISTOGRAMS, =1 NONE
      IF (IO(9).EQ.1) GO TO 10
C     CALCULATE AND PLOT HISTOGRAMS OF BOOST, COAST, AND TOTAL FUEL
```

```
      NDX=30
  950 CONTINUE
      CALL RANGE (WBOOST,IT,GREAT,SMALL,DX,NDX,ERRTB)
      IF (ERRTB .GT. 0 ) GO TO 960
      WRITE( 6,1360)
      CALL HISTO (WBOOST,IT,GREAT,SMALL,DX)
  960 CALL RANGE (WCOAS,IT,GREAT,SMALL,DX,NDX,ERRTB)
      IF (ERRTB .GT. 0 ) GO TO 970
      WRITE( 6,1370)
      CALL HISTO (WCOAS,IT,GREAT,SMALL,DX)
  970 CALL RANGE (WTOT,IT,GREAT,SMALL,DX,NDX,ERRTB)
      IF (ERRTB .GT. 0 ) GO TO 10
      WRITE( 6,1380)
      CALL HISTO (WTOT,IT,GREAT,SMALL,DX)
      GO TO 10
C
C     END OF MAIN ROUTINE    ONLY FORMAT STATEMENT FOLLOW
C
  980 FORMAT (/85H  SMPL  CAPT IMP   ROLL TORQ   BOOST IMP    T(WEB)
     1  T(TO)     BOOST FUEL      ISP/8X,77H(LB-SEC)  IMP(LB-SC)   (LB-S
     2EC)     (SEC)      (SEC)         (LBS)        (SEC))
  990 FORMAT (8F10.3)
 1000 FORMAT (/I5,1P7E12.4)
 1010 FORMAT (8X,44HCST TIME   FLOW RATE    NO. OF DB OVERSHOOTS,/10X,39
     1H(SEC)    FILTER IN   BOOST P-Y     ROLL)
 1020 FORMAT (5X,1P2E12.4,I8,I12)
 1030 FORMAT (8X,43HCST FUEL   FLOW RATE   NO. OF DB OVERSHOOTS,3X,10HTO
     1TAL FUEL,/,10X,40H(LBS)    FILTER IN   BOOST P-Y      ROLL,7X,5H(L
     2BS),/)
 1040 FORMAT (5X,1P2E12.4,I8,I12,4X,1PE12.4)
 1050 FORMAT (8X,55HCST TIME   FLOW RATE   FLOW RATE   NO. OF DB OVERSHO
     1OTS,/,10X,53H(SEC)    FILTER IN     COAST     BOOST P-Y      ROLL
     2,/)
 1060 FORMAT (5X,1P3E12.4,I8,I12)
```

```
1070 FORMAT (8X,66HCST FUEL   FLOW RATE   FLOW RATE     NUMBER OF DEADB
    1AND OVERSHOOTS,4X,10HTOTAL FUEL,/,8X,78H(POUNDS)   FILTER IN      C
    2OAST     BOOST P-Y     ROLL      COAST P-Y    (LBS) ,/)
1080 FORMAT (5X,1P3E12.4,I8,2I12,4X,1PE12.4)
1090 FORMAT (8X,69HCST TIME   FLOW RATE  DB RED TORQ  FLOW RATE     NUM
    1BER OF OVERSHOOTS,/,7X,81H(SECONDS)   FILTER IN   FUEL(LBS)     CO
    2AST     BOOST P-Y     ROLL      COAST P-Y,/)
1100 FORMAT (5X,1P4E12.4,I8,2I12)
1110 FORMAT (8X,93HCST FUEL   FLOW RATE  DB RED TORQ  FLOW RATE  RETRO 
    1TIME   NO. OF DB OVERSHOOTS    TOTAL FUEL,/,8X,89H(POUNDS   FILTER
    2 IN   FUEL(LBS)     COAST        (SEC)    BOOST P-Y ROLL CST P-Y   
    3 (LBS) ,/)
1120 FORMAT (5X,1P5E12.4,I8,2I6,4X,1PE12.4)
1130 FORMAT (//5X,11HPROBABILITY,6X,10HBOOST FUEL,7X,10HCOAST TIME,/23X
    1,8H(POUNDS),9X,9H(SECONDS),/)
1140 FORMAT (5X,F10.5,F16.3,F19.4)
1150 FORMAT (//22X,10HBOOST FUEL,7X,10HCOAST TIME)
1160 FORMAT (/5X,4HMEAN,11X,F11.3,F19.4)
1170 FORMAT (/5X,14HSTD. DEVIATION,F12.3,F19.4)
1180 FORMAT (//5X,42HFINAL VALUE OF RANDOM SEQUENCE INTEGER  = ,I20)
1190 FORMAT (/5X,38HNO. OF SAMPLES WITH DEADBAND OVERSHOOT)
1200 FORMAT (/10X,25HBOOST(PITCH AND YAW)    =,I8)
1210 FORMAT (/15X,20H(ROLL)              =,I8)
1220 FORMAT (/10X,25HCOAST                   =,I8)
1230 FORMAT (/5X,11HPROBABILITY,6X,10HBOOST FUEL,5X,10HCOAST FUEL,5X,10
    1HRETRO TIME,6X,10HTOTAL FUEL,/,23X,8H(POUNDS),7X,8H(POUNDS),7X,9H(
    2SECONDS),7X,8H(POUNDS),/)
1240 FORMAT (5X,F10.5,F16.3,F15.3,F16.4,F15.3)
1250 FORMAT (22X,10HBOOST FUEL,5X,10HCOAST FUEL,5X,10HRETRO TIME,6X,10H
    1TOTAL FUEL)
1260 FORMAT (/5X,4HMEAN,11X,F11.3,F15.3,F16.4,F15.3)
1270 FORMAT (/5X,14HSTD. DEVIATION,F12.3,F15.3,F16.4,F15.3)
1280 FORMAT (/5X,11HPROBABILITY,6X,10HBOOST FUEL,5X,10HCOAST FUEL,6X,10
    1HTOTAL FUEL,/,23X,8H(POUNDS),7X,8H(POUNDS),8X,8H(POUNDS))
```

```
1290 FORMAT (5X,F10.5,F16.3,F16.4,F15.3)
1300 FORMAT (/22X,25HBOOST FUEL     COAST FUEL,6X,10HTOTAL FUEL)
1310 FORMAT (/5X,*0.995 PROB*,5X,F11.3,F15.3,F16.4,F15.3,/,5X,*0.95 CON
    1FID*)
1320 FORMAT (I18)
1330 FORMAT (11I5)
1340 FORMAT (//)
1350 FORMAT (72H
    1                 /72H
    2                            )
1360 FORMAT (1H1,11X,*BOOST FUEL CONSUMPTION HISTOGRAM*,/)
1370 FORMAT (1H1,11X,*COAST FUEL CONSUMPTION HISTOGRAM*,/)
1380 FORMAT (1H1,11X,*TOTAL FUEL CONSUMPTION HISTOGRAM*,/)
1390 FORMAT (1H1,11X,*RETRO TIME HISTOGRAM*,/)
1400 FORMAT (1H1,5X,*DISTRIBUTION FUNCTION FIT*,/34X,*BOOST     COAST
    1   TOTAL*,//5X,*NORMAL DISTRIBUTION*,/)
1410 FORMAT (10X,*MEAN*,16X,3F10.3,/10X,*STANDARD DEV*,8X,3F10.3,/10X,*
    1SKEWNESS*,12X,3F10.3,/10X,*KURTOSIS*,12X,3F10.3,/10X,*0.995 PROB 0
    2.95 CONF*,3F10.3,/10X,*LEVEL OF SIGNIFICNCE*,3F10.3)
1420 FORMAT (/,5X,*LOG NORMAL DISTRIBUTION*,/6X,*(VALUES OF LOG)*)
1430 FORMAT (/,5X,*WEIBULL DISTRIBUTION*,/10X,*PARAMETERS A*,8X,3F10.4,
    1/21X,*B*,8X,3F10.4,/21X,*C*,8X,3F10.4,/10X,*PROBABILITY 0.5000*,2X
    2,3F10.3,/22X,*0.9900  *,3F10.3,/22X,*0.9950  *,3F10.3,/22X,*0.9990
    3  *,3F10.3,/10X,*LEVEL OF SIGNIFICANCE*,3F10.3)
1440 FORMAT (3(E10.3))
1450 FORMAT (E15.5)
1460 FORMAT (2(E15.5))
1470 FORMAT (I5/(6F10.3))
     END
```

```
*DECK ALTI
      SUBROUTINE ALTI (ALTO,VO,QO)
C     THIS SUBROUTINE COMPUTES THE ALTITUDE(ALTO) FROM THE
C     VELOCITY AND DYNAMIC PRESSURE USING THE ALTITUDE-DENSITY TABLE
      DIMENSION DUM(18)
      COMMON/DRH/RHO(18),MR
      MR=1
      RHI=ALOG(VO*VO/(2.*QO))
C     EXCHANGE THE ORDINATES AND ABSCISSAS IN THE ALTITUDE-DENSITY TABLE
      DO 10 J=1,18,2
      DUM(J)=RHO(J+1)
   10 DUM(J+1)=RHO(J)
      CALL TBLU (18,ALTO,RHI,DUM,MR)
      RETURN
      END
```

```
*DECK ASCEND
      SUBROUTINE ASCEND (L,VAL,M)
C     SUBROUTINE FOR REARRANGING ARRAY IN ASCENDING ORDER
C     OR DESCENDING ORDER IF M=1
      DIMENSION VAL(1)
      K=L-1
      DO 40 J=1,K
      KB=J+1
      DO 40 JL=KB,L
      IF(M) 10,10,20
   10 IF (VAL(J)-VAL(JL) .LE. 0 ) GO TO 40
      GO TO 30
   20 IF(VAL(JL)-VAL(J).LE.0) GO TO 40
   30 TEMP=VAL(J)
      VAL(J)=VAL(JL)
      VAL(JL)=TEMP
   40 CONTINUE
      RETURN
      END
```

```
*DECK CALCU
      SUBROUTINE CALCU
C     THIS SUBROUTINE COMPUTES THE STATE VARIABLES AND THE FIRST
C     DERIVATIVES FOR USE WITH THE RUNGE SUBROUTINE
      COMMON/DDI/TBL2(90),TBL3(90),NTHT,NWT,CDS,M2,M3,WBO
      COMMON/DDY/YDOT(4),Y(4),T,DT
      COMMON/DRH/RHO(18),MR
      DATA GO,RO,CON/32.174,20919668.,57.29577951/
      CALL TBLU (NTHT,TH,T,TBL2,M2)
      CALL TBLU (NWT,WT,T,TBL3,M3)
      ALT=Y(2)
      CALL TBLU (18,RHI,ALT,RHO,MR)
      Y(4)=0.5*Y(1)*Y(1)/EXP(RHI)
      G=GO/(1.+Y(2)/RO)**3
      GAMA=Y(3)/CON
      YDOT(1)=GO*(TH-CDS*Y(4))/(WT+WBO)-G*SIN(GAMA)
      YDOT(3)=-CON*(G*COS(GAMA))/Y(1)
      YDOT(2)=Y(1)*SIN(GAMA)
      RETURN
      END
```

```
*DECK CHISQ
      SUBROUTINE CHISQ (N,A,CR,NG,AM,AS,WA,WB,WC,LD)
C     THIS SUBROUTINE TEST THE SAMPLE DISTRIBUTION FOR GOODNESS
C     OF FIT TO A NORMAL, LOG-NORMAL, AND WEIBULL DISTRIBUTION FUNCTION
      DIMENSION A(1000),JCEL(100),Z(47),C(47)
      COMMON/CZ/Z,C
      DATA (Z(I),I=1,47)/
     1-1000.,-5.,-4.,-3.4,-3.2,-3.,-2.9,-2.8,-2.7,-2.6
     2,-2.5,-2.3,-2.1,-2.0,-1.8,-1.6,-1.4,-1.2,-1.0,-0.8,-0.6,-0.4,-0.2,
     30.,0.2,0.4,0.6,0.8,1.0,1.2,1.4,1.6,1.8,2.0,2.1,2.3,2.5,2.6,2.7,2.8
     4,2.9,3.0,3.2,3.4,4.0,5.0,1000.0/
      DATA (C(I),I=1,47)/
     1 0.,0.0000006,0.00006,0.0003,0.0007,0.0013,0.0019
     2,0.0026,0.0035,0.0047,0.0062,0.0107,0.0179,0.0228,0.0359,0.0548,
     3 0.0808,0.1151,0.1587,0.2119,0.2743,0.3446,0.4207,0.5000,0.5793,
     4 0.6554,0.7257,0.7881,0.8413,0.8849,0.9192,0.9452,0.9641,0.9772,
     5 0.9821,0.9893,0.9938,0.9953,0.9965,0.9974,0.9981,0.9987,0.9993,
     6 0.9997,0.99994,0.9999994,1.0/
      PN=N
      NPARM=4
      IF(LD.LE.0) NPARM=3
      XN=NG
      AB=A(10)
      AT=A(N-9)
      DV=(AT-AB)/(XN-2.)
      DO 10 J=1,NG
   10 JCEL(J)=0
      JCEL(1)=10
      JCEL(NG)=10
      NR=N-10
C     COUNT THE NUMBER OF VALUES  IN EACH GROUP
      DO 40 J=11,NR
      X=A(J)-AB
      IF(X) 20,30,30
```

```
   20 IC=1
      GO TO 40
   30 IC=X/DV+2
      IF(IC.GT.NG) IC=NG
   40 JCEL(IC)=JCEL(IC)+1
C     CALCULATE PROBABILITIES WITH EACH GROUP AND COMPARE ACTUAL WITH EX
C     SPECTED FREQUENCY AND COMPUTE CHI-SQUARED VALUE CS
C     COMPUTE LOWER CELL PROBABILITY
      XL=-1.E10
      XU=AB
      M=1
      FE=PN*PZC(XL,XU,AM,AS,WA,WB,WC,LD,M)
      FA=JCEL(1)
      CS=((FA-FE)*(FA-FE))/FE
C     COMPUTE UPPER CELL PROBABILITY
      XL=AT
      XU=1.E10
      M=46
      FE=PN*PZC(XL,XU,AM,AS,WA,WB,WC,LD,M)
      FA=JCEL(NG)
      CS=CS+((FA-FE)*(FA-FE))/FE
      NL=NG-1
      XL=AB
      M=1
      DO 50 J=2,NL
      XU=XL+DV
      FE=PN*PZC(XL,XU,AM,AS,WA,WB,WC,LD,M)
      FA=JCEL(J)
      CS=CS+((FA-FE)*(FA-FE))/FE
   50 XL=XU
C     TEST CHI-SQUARED VALUE FOR LEVEL OF SIGNIFICANCE
      F=NG-NPARM
      B=2./(9.*F)
      ZT=(1.-B-(CS/F)**0.3333333333)/SQRT(B)
```

```
M=1
CALL TBLN(CR,ZT,Z,C,47,M)
RETURN
END
```

```
*DECK CYCLE
      SUBROUTINE CYCLE (THEC,GR,DR,H,T1,T2,DC,A,NDOVER,FCT)
C     SUBROUTINE FOR COMPUTING THE LIMIT CYCLE
C        THEC=CONTROL ACCELERATION
C        GR=RATE TO DISPLACEMENT GAIN RATIO
C        DR=DEADBAND HALFWIDTH
C        H=HYSTERSIS
C        T1=EFFECTIVE TURN ON DELAY TIME
C        T2=EFFECTIVE TURN OFF DELAY TIME
C        DC=DUTY CYCLE
C        A=LIMIT CYCLE RATE
C        NDOVER=0 FOR NO DEADBAND OVERSHOOT
C              =1 FOR DEADBAND OVERSHOOT CONDITION
C        IF FCT IS GREATER THAN ZERO, PULSE WIDTH IS ESTIMATED AND USED
C        TO ESTIMATE EFFECTIVE CONTROL ACCELERATION
      NDOVER=0
      FK=1.0
      D=DR/57.3
      TDD=ABS(THEC)
      K=0
      IF (FCT .LE. 0 ) GO TO 10
      K=1
   10 A=(TDD*T2*(GR-T2/2.)+D*H)/(2.*GR-T1-T2)
      ALPHA=D*(2.*GR-T1-T2-H*(GR-T1/2.))/(T2*(GR-T2/2.)*(GR-T1/2.))
      IF (TDD-ALPHA .LE. 0 ) GO TO 20
      NDOVER=1
C     DUTY CYCLE APPROXIMATION FOR DEADBAND OVERSHOOT
      H=H/2.
      AD=2.*D*(1.0-H)/(TDD*GR)
      DNOM=(T1-T2+AD)/(2.*T2-AD+((AD/2.+T2-AD)*(T1-T2+AD)/GR))
      DC=1./(1.+DNOM)
      GO TO 30
C     COMPUTE DUTY CYCLE WITHOUT DEADBAND OVERSHOOT
   20 DC=FK/(1.+TDD*(D/A+T1-GR)/A)
```

```
      IF (K .LE. 0 ) GO TO 30
      PW=2.*A/TDD
      FK=1.0+FCT/PW
      TDD=ABS(THEC*FK)
      K=0
      GO TO 10
   30 RETURN
      END
```

```
*DECK HISTO
      SUBROUTINE HISTO (X,N,XMAX,XMIN,DX)
C     THIS SUBROUTINE SORTS AND PLOTS A HISTOGRAM ON THE LINE PRINTER
C        X=ARRAY OF SAMPLES
C        N=NUMBER OF SAMPLES IN ARRAY
C     XMAX=MAXIMUM VALUE
C     XMIN=MINIMUM VALUE
C       DX=INCREMENT FOR EACH CELL
C        K=NUMBER OF SAMPLES IN EACH CELL
      DIMENSION X(1),KAXIS(94)
      DATA ISTAR,IBLANK/1H*,1H /
C     PRINT NUMBER OF SAMPLES, MIN AND MAX VALUES
      WRITE( 6,110) N,X(1),X(N)
      L=1
      K=0
      AX1=XMIN
   10 AX2=AX1+DX
      DO 20 J=L,N
      IF (X(J)-AX2 .GE. 0 ) GO TO 30
      K=K+1
   20 CONTINUE
   30 IF (K-94 .GE. 0 ) GO TO 50
      K1=K+1
      DO 40 J=K1,94
   40 KAXIS(J)=IBLANK
      K2=K
      IF (K .LE. 0 ) GO TO 80
      GO TO 60
   50 K2=94
   60 DO 70 J=1,K2
   70 KAXIS(J)=ISTAR
   80 WRITE( 6,100) AX1,AX2,K,(KAXIS(J),J=1,94)
      IF (AX2-XMAX .GE. 0 ) GO TO 90
      L=L+K
```

```
      K=0
      AX1=AX2
      GO TO 10
   90 RETURN
  100 FORMAT (1X,F6.2,* TO*,F7.2,I5,* I*,94A1,*I*)
  110 FORMAT (1X,*NO OF SAMPLES=*,I5,*  MIN=*,F6.2,*  MAX=*,F7.2,/4X,*RA
     1NGE        NUMBER 0    5    10   15   20   25   30   35   40   45
     2 50   55   60   65   70   75   80   85   90   95*,/23X,*I....I....
     3I....I....I....I....I....I....I....I....I....I....I....I....I....I
     4....I....I....I....I*)
      END
```

```
*DECK OVRF
C     THIS SUBROUTINE COMPUTES A FACTOR(FAC) ON CONTROL MOTOR
C     THRUST FOR SHORT PULSES OF AN OVERSHOOT RESPONSE
C        T = TIME FROM ZERO THRUST TO FIRST OVERSHOOT PEAK
C        OR= THRUST OVERSHOOT RATIO FMAX/FPEAK
      SUBROUTINE OVRF (T,OR,FAC)
      A=0.31831*ALOG(1.0/(OR-1.0))
      P=ATAN(1.0/A)
      W=6.2832/T
      FAC=(1.570796-0.5*P-SIN(2.*P))/W
      RETURN
      END
```

```
*DECK PAGEHD
      SUBROUTINE PAGEHD (NRUN,NPAGE,NLINE)
C     THIS SUBROUTINE EJECTS AN OUTPUT PAGE AND PRINTS RUN NO.
C     AND PAGE NO. AT THE TOP OF EACH NEW PAGE
      WRITE( 6,10)
      WRITE( 6,20) NRUN,NPAGE
      NLINE=5
      RETURN
   10 FORMAT (1H1)
   20 FORMAT (5X,7HRUN NO.,I5,54X,8HPAGE NO.,I5)
      END
```

```
*DECK PZC
      FUNCTION PZC(XL,XU,AM,AS,WA,WB,WC,LD,M)
      COMMON/CZ/Z(47),C(47)
C     THIS FUNCTION SUBPROGRAM COMPUTES THE PROBABILITY OF A VALUE
C     BETWEEN A LOWER AND UPPER LIMIT FOR A NORMAL OF WEIBULL
C     DISTRIBUTION
      IF(LD.GT.0) GO TO 10
C     NORMAL DISTRIBUTION PROBABILITY
      SF=(XL-AM)/AS
      CALL TBLN(P1,SF,Z,C,47,M)
      SF=(XU-AM)/AS
      CALL TBLN(P2,SF,Z,C,47,M)
      PZC=P2-P1
      RETURN
C     WEIBULL DISTRIBUTION PROBABILITY
   10 P1=0.
      IF(XL-WA) 20,20,15
   15 AG=((XL-WA)/WB)**WC
      P1=1.-EXP(-AG)
   20 P2=0.
      IF(XU-WA) 30,30,25
   25 AG=((XU-WA)/WB)**WC
      P2=1.
      IF(AG.GT.100) GO TO 30
      P2=1.-EXP(-AG)
   30 PZC=P2-P1
      RETURN
      END
```

```
*DECK RANGE
      SUBROUTINE RANGE (X,N,XMAX,XMIN,DX,NDX,ERRTB)
C     THIS SUBROUTINE DIVIDES THE RANGE OF A TABLE OF NUMBERS INTO
C     N OR GREATER EQUAL PARTS WITH ESTHETICALLY PLEASING SCALES
C     TEST FOR INCREASING OR DECREASING FUNCTION.   IF DECREASING
C     THE TABLE IS CHANGED TO AN INCREASING ARRANGEMENT
C        X    = INPUT ARRAY
C        N    = NUMBER OF VALUES IN ARRAY
C        XMAX= UPPER END OF LAST CELL
C        XMIN= LOWEST VALUE
      DIMENSION X(1)
      ERRTB=0
C     TEST FOR ASCENDING OR DESCENDING ARRAY
      IF (X(1)-X(N)) 40,10,20
   10 ERRTB=1
      RETURN
C     DECREASING ARRAY, CHANGE TO ASCENDING ORDER
   20 LN=N/2
      DO 30 J=1,LN
      Z=X(J)
      NF=N+1-J
      X(J)=X(NF)
   30 X(NF)=Z
C     COMPUTE AESTHETICALLY PLEASING INCREMENTS OVER RANGE
   40 XMIN=X(1)
      XMAX=X(N)
      DELT=XMAX-XMIN
      ZDX=NDX
      XINC=DELT/ZDX
      XLIN=ALOG10(XINC)
      LIN=XLIN
      IF (XLIN .GE. 0 ) GO TO 50
      LE=-LIN+1
      GO TO 60
```

```
C
   50 LE=-LIN
   60 MINC=XINC*(10.**LE)
      IF (MINC-5 .LT. 0 ) GO TO 70
      XINC=5./(10.**LE)
      GO TO 100
   70 IF (MINC-4 .LT. 0 ) GO TO 80
      XINC=4./(10.**LE)
      GO TO 100
   80 IF (MINC-2 .GE. 0 ) GO TO 90
      XINC=1./(10.**LE)
      GO TO 100
   90 XINC=2./(10.**LE)
  100 DX=XINC
C    COMPUTE START AND FINISH  XMIN AND XMAX
      R=XMIN/XINC
      KAR=ABS(R)
      KR=R
      XKAR=KAR
C     TEST FOR FIRST CELL STARTING VALUE
      IF (KR .NE. 0 ) GO TO 130
      IF (R .LT. 0 ) GO TO 120
  110 XMIN=0.
      GO TO 160
  120 XMIN=-XINC
      GO TO 160
C     COMPUTE NON-ZERO MINIMUM STARTING CELL LOCATION
  130 IF (R) 140,110,150
  140 XMIN=-(XKAR+1.)*XINC
      GO TO 160
  150 XMIN=XINC*(XKAR-1.)
C     END CELL LOCATION
  160 XMAX=X(N)+XINC
      RETURN
      END
```

```
*DECK RNDX
      SUBROUTINE RNDX (JK)
C     SUBROUTINE FOR COMPUTING THE RANDOM NORMAL DEVIATE
C     RANF IS CDC BUILT-IN PSUEDO-RANDOM NUMBER GENERATOR
C     K IS THE CURRENT RANDOM SEQUENCE INTEGER WHICH CHANGES
C     WITH EACH NEW RANDOM NUMBER GENERATION
      COMMON K,RXD(30)
      DO 30 I=1,JK
      Q=RANF(K)
C THE FOLLOWING CODING WILL GIVE A SUITABLE REPLACEMENT FOR RANF
C     KA=K*23
C     JJ=1.0E+7
C     N=KA/JJ
C     M=N*JJ
C     K=KA-M-N
C     AK=K
C     Q=1.0E-7*AK
C  IN THE ABOVE OPTION K SHOULD BE A 7 DIGIT  NUMBER
C     TRANSFORM 0-1 UNIFORM DISTRIBUTION TO -0.5 TO 0.5 UNIFORM
      IF (Q-.5 .LE. 0 ) GO TO 10
      Q=1.0-Q
      AB=-1.0
      GO TO 20
   10 AB=1.0
C     TRANSFORM UNIFORM TO GAUSSIAN N(0,1)
   20 XPT=-2.*ALOG(Q)
      XRT=ABS(XPT)
      Y=SQRT(XRT)
      D=2.515517+.802853*Y+.010328*Y*Y
      E=1.0+1.432788*Y+.189269*Y*Y+.001308*Y*Y*Y
C     COMPLETE TRANSFORMATION TO GET RANDOM NORMAL DEVIATE
   30 RXD(I)=AB*(Y-(D/E))
      RETURN
      END
```

```
*DECK RUNGE
      SUBROUTINE RUNGE (L,I)
C     THIS SUBROUTINE PERFORMS THE RUNGE-KUTTA INTEGRATION IN
C     COMBINATION WITH THE CALCU SUBROUTINE
      DIMENSION RAT(4),SAV(4)
      COMMON/DDY/YDOT(4),Y(4),T,DT
      I=I+1
      GO TO (10,20,40,60,80), I
   10 L=1
      RETURN
   20 DO 30 J=1,3
      SAV(J)=Y(J)
      RAT(J)=YDOT(J)
   30 Y(J)=SAV(J)+0.5*DT*YDOT(J)
      T=T+0.5*DT
      L=1
      RETURN
   40 DO 50 J=1,3
      RAT(J)=RAT(J)+2.*YDOT(J)
   50 Y(J)=SAV(J)+0.5*DT*YDOT(J)
      L=1
      RETURN
   60 DO 70 J=1,3
      RAT(J)=RAT(J)+2.*YDOT(J)
   70 Y(J)=SAV(J)+DT*YDOT(J)
      T=T+0.5*DT
      L=1
      RETURN
   80 DO 90 J=1,3
   90 Y(J)=SAV(J)+(DT/6.)*(RAT(J)+YDOT(J))
      L=2
      I=0
      RETURN
      END
```

```
*DECK TABGEN
      SUBROUTINE TABGEN (QO,VO,GAMO)
C     THIS SUBROUTINE PROPAGATES THE TRAJECTORY PARAMETERS
C     VELOCITY,DYNAMIC PRESSURE, GAMMA, AND ALTITUDE DURING
C     A GRAVITY TURN BOOST.  INITIAL VELOCITY AND DYNAMIC
C     PRESSURE ARE USED TO DETERMINE ALTITUDE.  THRUST, WEIGHT
C     DRAG COEFFICIENT AND INITIAL FLIGHT PATH ANGLE(GAMMA) ARE
C     USED TO SOLVE THE EQUATIONS OF MOTION USING THE RUNGE
C     AND CALCU SUBROUTINES. RETURNED TABLES ARE VIA COMMON DOUT
      DIMENSION DUM(90)
      COMMON/DOUT/NQT,TBL1(90),NVT,TBL5(90),NGT,TBL6(90),NHT,
     1     TBL11(90),TF,NTC,TBL4(90)
      COMMON/DRH/RHO(18),MRH
      COMMON/DDI/TBL2(90),TBL3(90),NTHT,NWT,CDS,M2,M3,WBO
      COMMON/DDY/YDOT(4),Y(4),T,DT
      DATA DT,NP/0.5,4/
C     RHO IS A TABLE OF Z,P,Z,P,Z,P VALUES WHERE
C        Z = ALTITUDE IN FEET
C        P = NATURAL LOG OF INVERSE ATMOSPHERIC DENSITY(SLUGS/FT3)
C            ALOG(1/DENSITY)
      DATA (RHO(J),J=1,18)/0.,6.042,100000.,10.3417,120000.,
     1  11.271,140000.,12.1335,160000.,12.9239,200000.,14.3163,
     2  240000.,15.8823,328000.,20.665,557700.,27.256/
      DO 10 J=1,4
   10 YDOT(J)=0.
      MRH=1
      M2=1
      M3=1
C     COMPUTE INITIAL ALTITUDE FROM VELOCITY AND DYNAMIC PRESSURE
      CALL ALTI (ALTO,VO,QO)
      T=0.
      KP=NP
C     SET INITIAL TRAJECTORY STATES
      Y(1)=VO
```

```
      Y(2)=ALTO
      Y(3)=GAMO
      Y(4)=QO
C     BEGIN INTEGRATION LOOP AND FILLING OF TABLES
   20 IF (KP-NP .LT. 0 ) GO TO 30
      NQT=NQT+2
      NTQ1=NQT-1
      TBL1(NTQ1)=T
      TBL5(NTQ1)=T
      TBL6(NTQ1)=T
      TBL11(NTQ1)=T
      TBL11(NQT)=Y(2)
      TBL6(NQT)=Y(3)
      TBL5(NQT)=Y(1)
      TBL1(NQT)=Y(4)
      KP=0
   30 KP=KP+1
      I=0
C     CALL RUNGE-KUTTA INTEGRATION SUBROUTINE
   40 CALL RUNGE (L,I)
      IF (L.EQ.2) GO TO 50
C     CALL STATE EQUATION UPDATE SUBROUTINE
      CALL CALCU
      GO TO 40
   50 CONTINUE
      IF (T-TF .LE. 0 ) GO TO 20
C     END OF INTEGRATION LOOP
      NVT=NQT
      NGT=NQT
      NHT=NQT
      MD=1
C     CHANGE INPUT TABLE OF THETA-GAMMA TO NEW THETA TABLE
      DO 60 J=2,NGT,2
      T=TBL6(J-1)
```

```
      CALL TBLU (NTC,TH,T,TBL4,MD)
      DUM(J-1)=T
   60 DUM(J)=TH+TBL6(J)
      DO 70 J=1,NGT
   70 TBL4(J)=DUM(J)
      NTC=NGT
      RETURN
      END
```

```
*DECK TBLN
      SUBROUTINE TBLN (Y,X,T,A,NT,M)
C     THIS  SUBROUTINE IS A TABLE LOOKUP FROM ABSCISSA TABLE T
C     AND ORDINATE TABLE A .  Y IS ORDINATE AT GIVEN ABSCISSA X.
C     NT IS LENGTH OF TABLES T AND A. MIS LOCATION OF LAST VALUE  SOUGHT
      DIMENSION T(1),A(1)
   10 IF (T(M)-X) 50,20,30
   20 Y=A(M)
      RETURN
   30 IF (T(1)-X .LT. 0 ) GO TO 40
      M=1
      GO TO 20
   40 M=M-1
      GO TO 10
   50 MM=M+1
      IF (MM-NT .LE. 0 ) GO TO 60
      M=NT
      GO TO 20
   60 IF (T(MM)-X .GT. 0 ) GO TO 70
      M=MM
      GO TO 50
   70 M=MM-1
      DT=T(MM)-T(M)
      IF (DT .NE. 0 ) GO TO 80
      Y=A(M)
      RETURN
   80 DY=A(MM)-A(M)
      DDT=X-T(M)
      Y=A(M)+DY*DDT/DT
      RETURN
      END
```

```
*DECK TBLU
      SUBROUTINE TBLU (NT,Y,X,T,M)
C     SINGLE TABLE LOOKUP SUBROUTINE
C        NT = NUMBER OF VALUES IN ARRAY
C        Y  = RETURNED ORDINATE
C        X  = ABSCISSA VALUE CALLED
C        T  = INPUT TABLE OF ALTERNATING ABSCISSAS AND ORDINATES
C             ORDINATES MUST BE MONOTONICALLY INCREASING
C        M  = PREVIOUS INDEX USED IN THIS TABLE LOOKUP
C             THIS INDEX GETS CHANGED TO CURRENT VALUE
      DIMENSION T(1)
   10 IF (T(M)-X) 50,20,30
   20 Y=T(M+1)
      RETURN
   30 IF (T(1)-X .LT. 0 ) GO TO 40
      M=1
      GO TO 20
   40 M=M-2
      GO TO 10
   50 MM=M+2
      IF (MM-NT-1 .LE. 0 ) GO TO 60
      M=NT-1
      GO TO 20
   60 IF (T(MM)-X .GT. 0 ) GO TO 70
      M=MM
      GO TO 50
   70 M=MM-2
      DT=T(MM)-T(M)
      IF (DT .NE. 0 ) GO TO 80
      Y=T(M+1)
      RETURN
   80 DY=T(MM+1)-T(M+1)
      DDT=X-T(M)
      Y=T(M+1)+DY*DDT/DT
      RETURN
      END
```

```
*DECK THEMIN
      SUBROUTINE THEMIN (THEC,GR,DR,H,T1,T2,THMIN)
C     SUBROUTINE FOR COMPUTING  THE MINIMUM DISTURBING ACCELERATION
C     RESULTING IN ONE SIDED LIMIT CYCLE MOTION
C        THEC = CONTROL ACCELERATION
C        GR   = RATE TO DISPLACEMENT GAIN RATIO
C        DR   = DEADBAND HALFWIDTH
C        H    = HYSTERESIS
C        T1   = EFFECTIVE TURN-ON DELAY TIME
C        T2   = EFFECTIVE TURN-OFF DELAY TIME
C        THMIN= MINIMUM ACCELERATION (RETURNED)
      D=DR/57.3
      A=2.*GR-T1-T2
      B=(GR-T1/2.)*T1
      C=(GR-T2/2.)*T2
      Z=GR-T1
      ABC=(B-C)/A
      CA=C/A
      Z2=(D*H+C*THEC)/A
      Z22=(D*H-C*THEC)/A
      APR=B-Z*ABC-.5*(GR*GR+ABC*ABC)
      BPR=2.*D-Z*Z2-ABC*CA*THEC
      CPR=(.5*Z22*Z22+ABC*D*H/A)/APR
      XPR=.5*BPR/APR
      ZPR=ABS(XPR*XPR+CPR)
      ZPR2=SQRT(ZPR)
      THMIN1=ABS(XPR+ZPR2)
      THMIN2=ABS(XPR-ZPR2)
      IF (THMIN1-THMIN2 .GE. 0 ) GO TO 10
      THMIN=THMIN1
      GO TO 20
   10 THMIN=THMIN2
   20 RETURN
      END
```

```
*DECK WBL
      SUBROUTINE WBL (N,Y,NG,F)
C     THIS SUBROUTINE COMPUTES THE STATISTICAL DISTRIBUTION PARAMETERS
C     MEAN,STANDARD DEVIATION, SKEWNESS, KURTOSIS, GOODNESS
C     OF FIT TO NORMAL, LOG-NORMAL, AND WEIBULL
      DIMENSION Y(1),Q(20),R(18),S(24),X(1000),F(20)
      DATA (Q(I),I=1,20)/-0.95,3.46,
     1-0.87,3.0,-0.64,2.3,-0.37,1.8,-0.09,1.39,0.16,1.1,0.63,0.7,0.93,
     20.5,1.52,0.2,2.0,0.001/
      DATA (R(I),I=1,18)/0.,-0.001,0.4,-0.95,0.8,
     1-1.7,1.2,-2.43,1.8,-3.48,2.4,-4.55,3.0,-5.65,3.66,-6.92,4.5,-8.5/
      DATA (S(I),I=1,24)/0.,1.,0.2,0.932,0.4,0.902,0.6,0.888,0.8,0.886
     1 ,1.1,0.893,1.8,0.9275,2.2,0.947,2.6,0.963,3.0,0.974,3.5,
     2 0.984,4.5,0.994/
      MQ=1
      MR=1
      MS=1
      AVI=N-1
      XK=1./SQRT(1.-1.96*SQRT(2./AVI))
      NQ=20
      NR=18
      NS=24
      AN=N
      S1=0.
      S2=0.
      S3=0.
      S4=0.
      DO 10 J=1,N
      X(J)=Y(J)
   10 S1=S1+X(J)
C     COMPUTE THE MEAN VALUE
      XM=S1/AN
      DO 20 J=1,N
      DX=(X(J)-XM)
```

```
      DS=DX*DX
      S2=S2+DS
      S3=S3+DS*DX
   20 S4=S4+DS*DS
C     COMPUTE THE VARIANCE,SKEWNESS,KURTOSIS, AND STANDARD DEVIATION
      VAR=S2/AN
      SKEW=(S3/AN)/(VAR**1.5)
      SKUR=(S4/AN)/(VAR*VAR)
      SIG=SQRT(VAR)
C     COMPUTE THE A,B,C PARAMETERS FOR A WEIBULL DISTRIBUTION FUNCTION
      CALL TBLU (NQ,CL,SKEW,Q,MQ)
      C=EXP(CL)
      CALL TBLU (NR,BL,CL,R,MR)
      B=SQRT(VAR/EXP(BL))
      CALL TBLU (NS,A1,CL,S,MS)
      A=XM-B*A1
      OC=1./C
      F(1)=XM
      F(2)=SIG
      F(3)=SKEW
      F(4)=SKUR
      F(9)=XM+XK*2.576*SIG
      F(11)=A
      F(12)=B
      F(13)=C
      F(14)=A+B*(0.694**OC)
      F(15)=A+B*(4.6**OC)
      F(16)=A+B*(5.3**OC)
      F(17)=A+B*(6.9**OC)
C     USE CHI-SQUARED GOODNESS OF FIT TEST TO ESTIMATE LEVEL OF
C     SIGNIFICANCE (CR)
C     TEST WEIBULL DISTRIBUTION
      CALL CHISQ (N,X,CR,NG,XM,SIG,A,B,C,1)
      F(20)=CR
```

```
C     TEST NORMAL DISTRIBUTION
      CALL CHISQ (N,X,CR,NG,XM,SIG,A,B,C,0)
      F(18)=CR
      S1=0.
      S2=0.
      S3=0.
      S4=0.
C     COMPUTE THE LOGARITHM OF VALUES
      DO 30 J=1,N
      X(J)=ALOG(Y(J))
   30 S1=S1+X(J)
      XM=S1/AN
      DO 40 J=1,N
      DX=(X(J)-XM)
      DS=DX*DX
      S2=S2+DS
      S3=S3+DS*DX
   40 S4=S4+DS*DS
      VAR=S2/AN
      SIG=SQRT(VAR)
      SKEW=S3/(AN*VAR**1.5)
      SKUR=S4/(AN*VAR*VAR)
      F(5)=XM
      F(6)=SIG
      F(7)=SKEW
      F(8)=SKUR
      F(10)=EXP(XM+XK*2.576*SIG)
C     TEST LOG-NORMAL DISTRIBUTION FOR LEVEL OF SIGNIFICANCE
      CALL CHISQ (N,X,CR,NG,XM,SIG,A,B,C,0)
      F(19)=CR
      RETURN
      END
```

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16 Abstract
This report describes a FORTRAN coded computer program and method to predict the reaction control fuel consumption statistics for a three axis stabilized rocket vehicle upper stage. It uses a Monte Carlo approach which is made more efficient by using closed form estimates of impulse useage. It includes effects of rocket motor thrust misalignment, static unbalance, aerodynamic disturbances, and deviations in trajectory, mass properties and control system characteristics. This routine has been used for over a decade to accurately predict the control fuel consumption statistics for the Scout launch vehicle second and third-stage reaction control systems.

By selection of input data and options this routine can be applied to many types of on-off reaction controlled vehicles.

The psuedo random number generation and statistical analyses subroutines including the output histograms can easily be used for other Monte Carlo analyses problems.

A typical run of 200 samples requires 2 seconds of central processor time on a CDC CYBER 175 computer.

17 Key Words (Suggested by Author(s))
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